PARKING STRUCTURE DETERIORATION:
A SURVEY AND ANALYSIS
OF ITS EXTENT AND INFLUENCING FACTORS
VOLUME I REPORT

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by

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PREFACE AND ACKNOWLEDGEMENTS

This study was conducted by Trow Ltd. for Supply and Services Canada under Contract # 05SU-1 P001-3-5640-21 and represents a major attempt to assess and analyse the problems of parking structure deterioration in Canada.

Financial and technical assistance was provided by the following agencies in the development of this report.

- **Canada Mortgage and Housing Corporation**
- **National Research Council of Canada**
- **Public Works Canada**
- **Supply and Services Canada**

This report was prepared by Trow Ltd. under the guidance of a Steering Committee comprised of representatives from Canada Mortgage and Housing Corporation, National Research Council, Department of Public Works and Supply and Services Canada. Its content also reflects valuable input received from a broad cross section of the many projects in which Trow Ltd. has been separately involved over the last seven years.

Specific guidance on matters relating to the Ontario Housing Corporation portfolio of Parking Structures was provided by Ric Waddell of their Ottawa Branch. Kerry Thompson of Public Works Canada provided valuable insight into the design and use of parking structures in large public buildings.

Trow Ltd. wishes to thank all of those individuals who participated in the preparation of this publication and hopes that the Report will prove to be a useful addition to existing Canadian literature in this field. The author anticipates that it will be of particular value to those professionals and contractors involved in the survey and rehabilitation of existing structures and the design of new ones.

EXECUTIVE SUMMARY

INTRODUCTION

The deterioration of parking structures is now a cause of serious alarm. The main problem is corrosion caused by road salt and water which, because of improper sealing of the surfaces, penetrate the concrete. Construction and environmental factors and maintenance procedures are the key elements in this deterioration. The problem is widespread and estimates place the cost of damage to the country's inventory of parking structures in the range of $1 billion to $3 billion.

Several independent technical committees, among them the American Concrete Institute (ACI) and the Canadian Standards Association, are now examining the phenomenon of deteriorating parking structures and developing new codes of practice.

This present study, a survey and analysis of the extent of deterioration in over 300 parking structures and the factors influencing this deterioration, delineates the technical dimensions of the problem and offers some guidelines for ameliorating the condition of existing structures and preventing the problem in new structures.

OBJECTIVES

The objectives of this study were as follows:

- to identify those factors that favourably affect the serviceability of parking structures so that the characteristics that have resulted in durable structures could be isolated;
- to identify those cost-effective repair procedures that could be used in present and future repair programs of the contributing departments and CMHC;

- to identify suitable operation and maintenance procedures to be used after repairs are made;
- to make information available for incorporation into the relevant codes, by the appropriate committees, which objective will be achieved by the publication of this report.

GEOGRAPHICAL SCOPE OF SURVEY

The surveys took place in Montreal, Ottawa and the Toronto Region. A uniform methodology of survey, previously developed by Trow, was used throughout the study. Field surveys of garages nominated by the sponsoring departments, additional garages from the Ontario Housing Corporation's stock, nominated garages from the municipality of North York and Garage Condition Survey data from previous independent work by Trow Ltd., already on file, have been used. The study is primarily concerned with multi-storey, cast-in-place, underground parking garages. Precast concrete structures and any structure system with built-in cathodic protection were excluded.

METHODOLOGY

Much technical data have been derived from field studies. The damaged areas investigated were usually 10% of the total slab area. The field work consisted of:

- visual survey
- chain drag delamination survey, to determine by sonic means the extent of the damage
- electrical half-cell survey
- covermeter survey
- component inspection and coring.

Laboratory testing included compressive strength, absorption, density, chloride content, air void system, and chloride permeability determinations.

CONCLUSIONS

I The data assessed in this study shows that durable new garages can be built. To achieve the goal of durable new reinforced concrete parking facilities, attention must be paid to a number of details during the design, construction and use of the properties.

a) In design, attention must be paid to achieve:
- good drainage from around columns and from slabs
- crack-free slabs by the use of post-tensioning systems
- good quality expansion joints and other provisions for slab movements
- adequate concrete cover and the use of wear resistant waterproof systems.

b) In construction, on- site inspection to ensure:
- adequate and uniform cover of good quality concrete
- the presence in the delivered concrete of specified air-void systems and other additives
- the prevention of construction-induced deflection or cracking (resulting from premature formwork removal)
- good drainage requirements are met.

c) During use, careful attention to:
- regular maintenance schedules
- prompt resealing or repair of cracks and spallings.

II The data also shows that rehabilitation of existing damaged parking structures is possible by the use of known materials and techniques. Deterioration after repair and waterproofing is, however, inevitable, unless all active chloride contaminated concrete is removed. After concrete repairs and waterproofing have been completed, subsequent rates of deterioration are substantially lower than the rate of deterioration prior to repair.

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1.0 INTRODUCTION

The deterioration of parking structures has become a cause of serious alarm. There is now an acceptance on the part of owners, industry and government agencies that this deterioration is widespread and represents a potential monetary loss to owners and mortgage insurers of very large sums of money.

The problem of deterioration is an insidious one and one that is very difficult to remedy. The main problem is that no one owner or authority owns more than a small number of structures. Most have been operating in ignorance of one another's problems, and, therefore, little coordinated research has taken place.

The main damage is caused by road salt and water. This joint attack results in the breakdown of concrete because of corrosion, potentially to the point of collapse. Once corrosion becomes evident on visual survey, it is usually past the point of easy repair.

The penetration of the concrete by water and salts occurs when concrete surfaces are not properly sealed. Construction practice and environmental factors play a part in the way the finished structure performs; use and maintenance practices are also critical to the successful performance of the parking structure.

The problem has now been widely recognized. Many owners, such as Public Works Canada and CMHC, are aware of the magnitude of the problem and are already faced with major fund commitments.

Some research has already been done in Canada. Much more is required, but more important is the need for systematic research and the coordination of this research. Various interested institutions have set up committees to investigate the problem. The Ontario Chapter of the American

Concrete Institute published a guideline document in August 1981.(16) ACI Committee 362 hopes to have a State of the Art Statement available by early 1985 and a guideline document by 1985/86. A Code of Practice covering both the investigation and the repair of old structures will also provide design and construction criteria for new structures by 1988/89. In 1983, the Canadian Standards Association set up a committee entitled "The Design, Construction and Maintenance of Durable Parking Structures". A Standard is expected in 1985/86. The overall problem and the professional and institutional activities involved in resolving it are shown in Figure 1.

In 1981, CMHC commissioned a visual survey of 84 parking structures attached to apartment buildings in the Ottawa area. It subsequently published the results in a report entitled "The Nature, Extent and Impact of Residential Parking Structures' Deterioration".(22) This was the first survey of its kind in Canada. As a result of this survey, and discussions with others engaged in similar research, CMHC decided to proceed with the present study, in cooperation with the National Research Council, Public Works Canada and Supply and Services Canada.

The objectives of this study were agreed to be as follows:

- to identify those factors that favourably affect the serviceability of parking structures so that the characteristics that have resulted in durable structures could be isolated;

- to identify those cost-effective repair procedures that could be used in present and future repair programs of the contributing departments and CMHC;

- to identify suitable operation and maintenance procedures to be used after repairs are made;

- to make information available for incorporation into the relevant codes, by the appropriate committees, which objective will be achieved by the publication of this report.

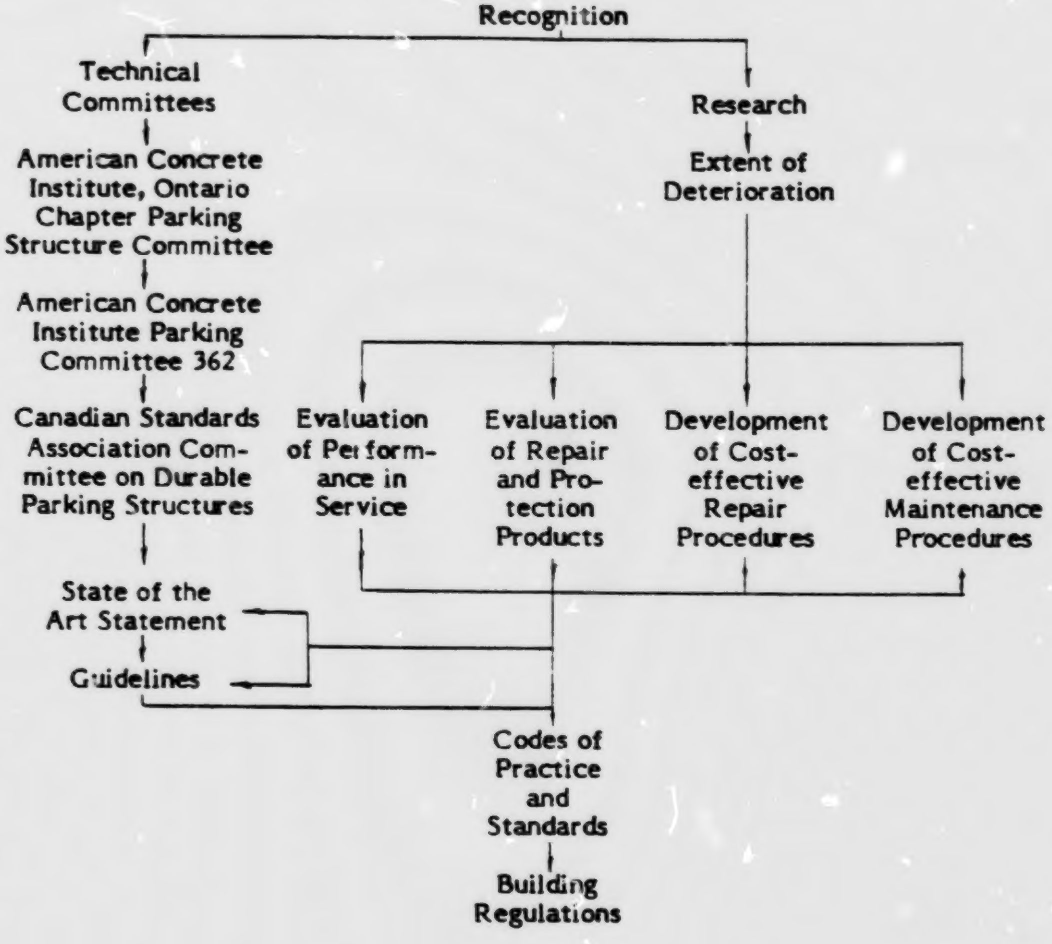
The study scope was as follows:

- evaluation of data already available from Trow files on garage condition surveys;
- field surveys of garages, field sampling and laboratory testing;
- assessment of estimated total damage;
- analysis of design and construction practices that have affected the durability of the structures;
- discussion of repair and protection systems that can be shown to provide cost-effective repairs.

The survey was limited to the main urban areas of Montreal, Ottawa and Toronto and a small sample from the Maritimes. The survey excluded any consideration of pre-cast concrete structures, and any cathodic protection systems. It was primarily concerned with multi-storey cast-in-place concrete underground parking structures.

The total problem and the phases involved in resolving it can be represented as follows in Fig 1.

Fig 1.


Recognition
Technical Committees
American Concrete Institute, Ontario Chapter Parking Structure Committee
American Concrete Institute Parking Committee 362
Canadian Standards Association Committee on Durable Parking Structures
State of the Art Statement
Guidelines
Research
Extent of Deterioration
Evaluation of Performance in Service
Evaluation of Repair and Protection Products
Development of Cost-effective Repair Procedures
Development of Cost-effective Maintenance Procedures
Codes of Practice and Standards
Building Regulations

2.0 METHODOLOGY

2.1 General

The sources from which the data were obtained, the reasons for using these sources, and the technical procedures used to obtain the data are described below. Where appropriate, because of novelty or where it is thought wider understanding is desirable, some description of these technical procedures is included.

The overall sample from which the data were obtained comprised approximately 310 garages, mostly located in Ontario but with a small number from Quebec and a few from the Maritimes. Sixty seven parking structures were surveyed as part of this project. To protect the anonymity of the owners, numbers have been assigned to them. The sample is clarified in Table 1.

Table 1

Garage Sample

Project Series	Number of structures In Series	Number Surveyed In This Project	Remarks
a	16	16	Part of sample of 84 in original CMHC survey.
b	4	4	Detailed surveys
c	11	11	Monitoring surveys
d	11	11	
e	22	22	Part of sample of 159 in OHC survey.
f	3	3	
	67		
Trow Data Base*	175	--	
Totals	242	67	
Balance of CMHC Survey**	68		
Total Sample	310		

* This data base was used to provide background norms for various aspects of this investigation.

** Data from these 68 structures examined in 1981, provided additional design information for comparison purposes.

In this study, three series of structures, "a", "b", and "e", were originally surveyed as the sample expected to produce enough examples of durable structures to answer the question "Why are the good ones good?". Few underground garages in active use met these criteria, in that almost all exhibited significant distress, that is 10% delamination or more. Two other series were therefore added, series "d" and "f". Series "d" structures were surveyed to broaden the sample base, to see if above ground structures had proved to be more durable than the underground ones. Series "f" structures were three structures in North York reported as being durable.

The sixth series, the "c" structures, were repaired garages where details of repairs were available. These were surveyed to determine the effectiveness of the repairs, by measuring any further deterioration that had occurred after repairs were made.

In addition to the above six series, Trow also used data from its own surveys of 175 parking structures.

The complete survey reports for series "a" to "f" are deposited with the Canadian Housing Information Centre at CMHC. The findings of these surveys are summarized and reviewed in this report. The series of structures examined are listed below, together with the relevant information that explains their choice.

2.2 "a" Structures (a1-a16)

These 16 structures were part of those surveyed for CMHC in 1981.(22) At that time, a preliminary assessment was made, without engineering investigation, of the financial impact of the cost of repairs to 84 residential parking structures in the Ottawa area. The original sample was reviewed for the present investigation and all garages previously surveyed for which repairs had been estimated as less than $100 per parking space were considered for resurvey. A letter was sent in 1983 to the owners of the 20 garages which fell within this category. Positive replies were received from 16 of the 20 owners and these 16 garages were resurveyed visually.

For the Ottawa parking facilities resurveyed under this section of the sample, a simple methodology was adopted. The building profile was characterized in a simple sketch and basic data was obtained about age, size of parking facilities, type of construction, details of repairs and/or waterproofing, and current condition. Other relevant remarks were noted.

2.3 "b" Structures (b1-b4)

These were the structures surveyed in detail as part of this program. Following is their description. They were:

b1 An underground garage in office and shopping mall complex in Ottawa.

b2 An above ground, free standing, post-tensioned structure in Toronto.

b3 An above ground, free standing, reinforced concrete structure in Toronto.

b4 An underground garage in an office and shopping mall complex in Montreal.

2.4 "c" Structures (c1-c11)

A small number of parking structures, listed below by location, were nominated by CMHC and Public Works for monitoring of the effectiveness of repair systems.

c1 An underground garage in an Ottawa Government Office.

c2 An underground garage in a Hull office and shopping mall complex.

c3 An underground garage in a Toronto Government Office.

c4 A Toronto condominium (low to average income).

c5 An outside parking structure in Kitchener.

c6 An outside parking structure in a hospital in Toronto.

c7 An outside parking structure in a shopping centre in Hamilton.

c8 An underground garage in a rental complex in Toronto, built and owned by a Developer.

c9 An underground garage in a large apartment complex in Montreal.

c10 An underground garage in a bank and shopping mall building in Montreal.

c11 An underground garage in an apartment building in London.

2.5 "d" Structures (d1-d11)

Towards the end of the project, when it became obvious that, with a few special exceptions, multi-storey underground garages all had some degree of deterioration, it was decided to expand the sample base somewhat, to include a small number of different types of above-surface garages which were believed to be in good condition, in order to confirm that there are, indeed, some types and systems of structures which are performing better than the average underground parking structure. These above ground structures were surveyed on a visual basis in the manner outlined in Section 2.9.

2.6 "e" Structures (e1-e22)

In 1982, the Ontario Housing Corporation, using its own forces, carried out a survey of its 159 parking structures in Ontario.

In its survey, OHC rated structures from 1 (no significant deterioration) to 10 (extremely advanced state of deterioration). For the purposes of this present report, it was decided that it was not prudent to select suitable structures for detailed survey from these 150 without first viewing a sample. A preliminary survey was made of the 22 structures in Toronto that had been placed in categories 1 and 2 of the OHC survey.

The survey took the form of a visual survey in which the main characteristics of each structure and its condition were noted; in addition the degree of use of the structure was ascertained.

2.7 "f" Structures (f1-f3)

Starting in the Summer of 1983, the Building Commissioner of North York, Ontario, commenced a survey of all parking structures within his jurisdiction. Trow Ltd. were involved in a consulting capacity with the survey team. As the problem of finding a multi-storey underground garage in good condition became a major problem in the sample selection for this study, the North York survey team was contacted and asked whether it had found any underground parking structures in good condition. Out of approximately 100 garages inspected up to that time, the North York team found only three that they felt appeared to meet our requirements. These three became the "f" series structures.

These 3 garages were therefore surveyed in a similar manner to those of the Ontario Housing Corporation ("e" series).

2.8 Trow Data Base

As part of the provision of its range of professional services, Trow Ltd. carries out condition surveys of parking structures for private clients. To date, in excess of 175 structures have been surveyed. These surveys range from brief superficial visual surveys for a variety of objectives to detailed surveys from which the extent and nature of damage can be assessed in a quantitative and qualitative manner for repair contract document preparation.

This data base has been used to provide background norms for various aspects of this investigation. It will be noted that the sample number for each aspect for which this data base is used varies considerably. This is simply because, in the majority of cases, the surveys do not involve extensive testing and the surveys for which this data base is used to provide norms are restricted to those where significant test data is available.

In presenting data from the Trow Ltd. data base, and in some cases the evaluation of field test data in the detailed surveys made in connection with this project, standard arithmetical and statistical procedures have been used. In addition, standard methods of graphical presentation have also been adopted. Where applicable, regression analysis has also been used to evaluate data.

2.9 Methodology for Visual Surveys

Initially, a detailed format was designed and proposed for visual surveys. After field trials of this system in the North York survey, it was decided that a form system was too complex as a survey record document, although useful as a detailed checklist. Accordingly, a simpler format of field survey form was designed. In the event, as the program progressed, it was decided that for the visual surveys an even briefer and simpler format was both adequate and appropriate. The format used for the simpler form of field survey form is attached as Appendix B.

2.10 Methodology for Detailed Surveys (Series "b")

2.10.1 Fieldwork

Test areas were investigated on interior suspended slabs. These areas were chosen to be representative of the condition of the total area, based on the visual judgement of the engineer/technician in charge of the field survey. The area investigated was usually approximately 10% of the total area. The locations of the tests areas are shown on the survey reports deposited with CMHC. Fieldwork consisted of the following:

1. Grid layout
2. Delamination survey
3. Visual survey (similar to 2.9)
4. Half-cell survey
5. Covermeter survey
6. Component survey
7. Coring

2.10.2 Grid Layout

The test areas were divided into a 2 x 2 m grid system using the columns and perimeter walls as reference points.

2.10.3 Delamination Survey

The test areas were fully investigated for possible delaminations within the concrete.

Determination of the possible delaminations within the concrete slab was made using the chain-drag method. This is a simple sonic method in which a heavy steel chain is dragged across the surface and areas of delamination are characterized by a dull sound. Chain-dragging is well established as an effective method to determine delaminations. Trow were using the technique experimentally in garage investigations in 1975 and extensively in bridge deck condition surveys in the summer of 1977. Based on that experience this was made a standard procedure for garage investigations from 1977 onwards.

Cores were then obtained from some of the delaminated areas in order to establish their depth and severity.

2.10.4 Visual Survey

This phase of the operation consisted of mapping cracks, spalls, impending spalls, exposed reinforcing bars, leaching and honeycombing on the complete soffit of the suspended levels and on the top surface of the test areas.

2.10.5 Half-Cell Survey

A survey of the test areas for corrosion activity was carried out using a copper-copper/sulphate half-cell. This method is based on ASTM Standard C876-77 "Half-Cell Potentials of Reinforcing Steel in Concrete". The method consists of connecting a wire to the cleaned exposed top reinforcing bar, and connecting from this point, via a voltmeter, to the copper-copper/sulphate half-cell, which is placed at each grid point. A typical grid would have a 2 x 2 m spacing. The potential of the steel reinforcement within the structure is then determined.

The measured voltage potential can be related to the corrosion activity of the reinforcing steel. At the start of each day a resistance check is made between two exposed bars. When base connections are changed, compatibility with previous results is checked and overall assessments of data are made on a daily basis.

If potentials over an area are numerically less than -0.20 V CSE, there is a greater than 90% probability that no reinforcing steel corrosion is occurring in that area at the time of measurement. If potentials over an area are in the range of -0.20 to -0.35 V CSE, corrosion activity of the reinforcing steel in that area is uncertain. If potentials over an area are numerically greater than -0.35 V CSE there is a greater than 90% probability that reinforcing steel corrosion is occurring in the area, at the time of measurement. All voltages are referenced to the copper-copper/sulphate (CSE) half-cell.

Cracks occurring in the concrete are potential paths for water penetration. This water penetration, carrying dissolved salts, particularly chlorides, presents the same problems to the underside steel. They are generally first evident by the deposition of leached material at the egress of the crack on the underside of the slab.

The half-cell readings primarily indicate where corrosion occurring in the top reinforcing is likely to produce delaminations in the future. Cracking through the slab can influence the magnitude of some of the half-cell values recorded. Readings influenced by the corrosion of the bottom steel will not influence the determination or indication of delamination on the top surface of the slab.

2.10.6 Covermeter Survey

A survey of the approximate cover to the top reinforcing steel in the test areas was carried out using a James Electric R-Meter. The method is based on British Standards Institution Standard BS 4408: Part I: 1969, "Recommendations for Non-Destructive Methods of Test for Concrete Part I Electro-Magnetic Cover Measuring Devices".(1) The test uses an Electro-Magnetic detecting instrument which responds in a quantitative manner to ferrous metals. It is calibrated to measure the concrete cover to steel for a known bar size. The bar size was verified by a visual examination of bars exposed by coring. At the start of each day in the field and periodically thereafter, physical checks of the accuracy and functioning of the meter were made, by reference to locations, such as core holes, where the cover to bars could be physically measured. The accuracy of the meter used is normally approximately ± 3 mm up to 38 mm, and ± 6 mm over 38 mm of concrete cover.

2.10.7 Component Inspection

A visual survey was made of those components, other than the parking levels slabs, that form the parking structure.

2.10.8 Coring

Cores were obtained from the test areas to:

(i) Determine the chloride ion content in the concrete.
(ii) Determine the compressive strength of the concrete.
(iii) Verify delaminations within the concrete slabs.
(iv) Obtain electrical contact with the reinforcement for the corrosion survey.
(v) Verify the condition of the reinforcing steel.
(vi) Determine the air void system of the concrete.

A diamond drill was used to obtain 100 mm diameter cores. Locations were chosen to be representative of the overall structure. These cores include those removed for the half-cell tests. Details of the cores are recorded in the core log at the end of each report, and the core locations are shown on the report drawings deposited with CMHC. The samples of concrete removed by coring were returned to the Trow laboratory where the in-place properties of the concrete, were determined with particular reference to the chloride ion content and the compressive strength.

2.10.9 Laboratory Testing

2.10.9.1 Chloride ion content

For this study, cores were cut horizontally and a slice at the level of the top steel was tested for water soluble chloride ion content of the concrete, in accordance with Report FHWA-RD-77-85. This is the standard analytical procedure in use in Ontario.

To ensure a high degree of confidence in test results, tests are made annually by the MTC in Ontario to determine the interlaboratory values for this standard soluble-chloride-ion content test. In view of a lack of published data on the precision and accuracy of this test, the following results obtained in 1983 are of interest.

Two basic samples were chosen, one with a chloride ion content approximately equal to the threshold value for corrosion and the other with a chloride ion content approximately ten times this value. In both cases the number of replicates was two and the number of laboratories involved in the round robin tests was eleven.

For the first sample, the average chloride content found was 0.026% by weight of the concrete and, for this sample, the "within-laboratory" coefficient of variation was 3.4 % and the "between-laboratory" coefficient of variation 5.2 %.

For the other sample the average chloride content was 0.263 % and, for this sample, the "within-laboratory" coefficient of variation was 1 % and the "between-laboratory" coefficient of variation 3.6 %.

It will be seen therefore that it is a reliable test procedure, with very low "within-laboratory" and "between-laboratory" variations.

2.10.9.2 Compressive strength

Those cores, that were judged suitable for testing were tested for compressive strength, in accordance with CSA Standard A23.2-14C, 1977, "Obtaining and Testing Drilled Cores for Compressive Strength Testing".

2.10.9.3 Chloride permeability

While the distance from the slab surface to the reinforcing steel will influence the time it takes chlorides to penetrate to the steel, a major factor will also be the permeability of the concrete. The greater the permeability of the concrete, the more rapidly penetration of chlorides, to the steel, will take place.

Clearly, it is desirable that either the concrete or concrete toppings are themselves highly impermeable, or that sealers and waterproofing systems make the concrete deck adequately impermeable.

Until recently, the most commonly used test procedures for determining the chloride permeability of concrete was AASHTO T 259-80 "Resistance of Concrete to Chloride Ion Penetration". This procedure consists of applying a 3 % sodium chloride solution to the surface of a concrete slab specimen for ninety days. The concrete is then sampled at various depths and the chloride content determined.

Recently a new rapid test procedure was developed, by the Portland Cement Association for the Federal Highway Administration.

In the laboratory test, the method consists of monitoring the amount of electrical current passed through a concrete core test specimen, when a potential difference of 60 volts D.C. is maintained across the specimen for six hours. Chloride ions are forced to migrate out of a sodium chloride solution, when subjected to a negative charge through the concrete towards a copper-mesh screen the screen fulfills the function in the test system that reinforcement would in a structure. Current versus time is integrated, to obtain the total charge (in coulombs) passing through the tests specimens during the test period.

The laboratory test uses 100 mm cores, 50 mm long. These can easily be obtained from structures at any time. Thus, concretes surface treatments, either sealers or waterproofing systems, can be easily tested by this method. The test cell is shown diagrammatically in Figure 2.

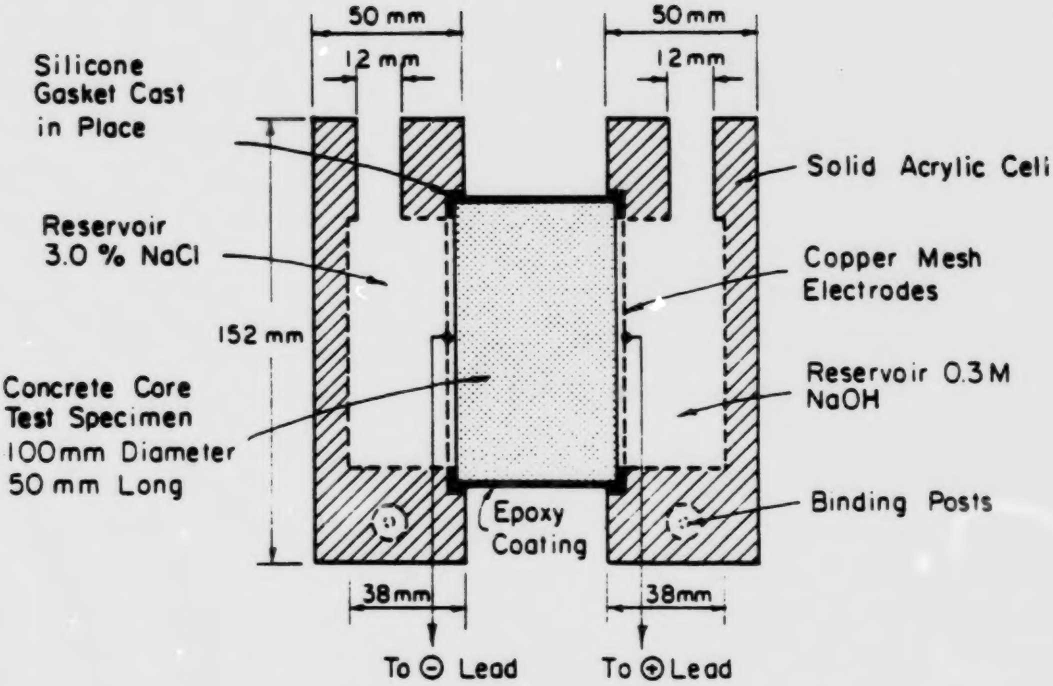

50 mm
12 mm
50 mm
12 mm
Silicone Gasket Cast in Place
Solid Acrylic Cell
Reservoir 3.0 % NaCl
Copper Mesh Electrodes
152 mm
Concrete Core Test Specimen 100mm Diameter 50 mm Long
Reservoir 0.3 M NaOH
Binding Posts
Epoxy Coating
38mm
38mm
To ⊖ Lead
To ⊕ Lead

FIG. 2 APPLIED VOLTAGE CELL FOR CORE SPECIMEN

In the work reported here, tests consisted of sets of either two or three 100 mm diameter core specimens 50 mm long.

For the evaluation of test results, Table 2, established by Whiting (53) is used.

Table 2
Interpretation of Results

Chloride Permeability	Charge Passed (coulombs)	Type of Concrete
High	4,000	High water-cement ratios (0.6)
Moderate	2,000 to 4,000	Moderate water-cement ratio (0.4 to 0.5)
Low	1,000 to 2,000	Low water-cement ratios "Iowa" dense concrete
Very Low	100 to 1,000	Latex modified concrete Internally sealed concrete
Negligible	100	Polymer impregnated concrete Polymer concrete

As will be seen from this table, the lower the total electrical charge passed (in coulombs) the more impermeable the concrete or surface treatment. The best possible performance is a zero reading.

2.10.9.4 Air void system

Polished sections were tested in accordance with ASTM C457-82 "Microscopical Determination of Air-Void Content and Parameters of the Air-Void System in Hardened Concrete".

This test determines total air content, the size of air bubbles in terms of specific surface, and the spacing factor or average distance between air bubbles.

2.11 Identification of Proprietary Materials

In the monitoring surveys c1-c11, which determined the effectiveness of various repair systems, it was not considered appropriate to identify the products involved. The following are generic descriptions of these products.

Product Identification	Generic Description
W-1	Applied-in-place, short, alkali-resistant glass fibre reinforced cementitious topping.
W-2	Applied-in-place, rubberized-asphalt waterproofing membrane with a divorcing sheet and a mastic asphalt wearing course.
W-3	Applied-in-place, latex-neoprene waterproofing membrane with a coal tar epoxy wearing course.
W-4	Applied-in-place, two-component polyurethane waterproofing membrane with a polyurethane and sand mix wearing course.
W-5	Applied-in-place, coal-tar-epoxy waterproofing system reinforced with a fibreglass sheet and surfaced with silica sand.
W-6	Applied-in-place, rubberized-asphalt polymer waterproofing membrane with a latex-rubberized-asphalt wearing course.
I-1	Applied-in-place, cementitious waterproofing system, containing catalytic chemicals and treated quartz.
S-1	Applied-in-place, two-component, solvent-based solution of flexible epoxy resin.

The performance data relating to these materials is summarised in Table 19, Section 5.

3.0 FINDINGS

3.1 Condition Survey Study Data

3.1.1 "(a)" Series Structures

The sixteen garages which formed this part of the survey were those which were identified in the original CMHC research programme as having little or no damage at the time of the original survey. These structures were resurveyed and a number of characteristics became obvious. They consisted of slabs on grade with a roof, some of which were internal or partially internal. All of the garages were small roof-parking structures varying from 0 to 150 spaces, with an average of 30, or interior parking ranging from 8 to 231 with an average of 70 spaces. None of the structures contained a suspended slab.

Eleven of the structures were waterproofed and, on three of the roofs, the area was partially or wholly landscaped. Generally the roofs gave evidence of traditionally good waterproofing practices, the systems being flashed vertically to all exposed surfaces and traditional flashings being evident in all places. In addition, drainage was generally excellent and in good condition.

With regard to the two roofs which were not waterproofed, one was not used for parking and the other was well drained. It should be noted that the latter was exhibiting some signs of deterioration at the time of the second survey.

These were simple, generally rigid, structures of small size, and were not typical of the underground garages which form the major part of the inventory of badly deteriorated structures.

3.1.2 "(b)" Series Structures

These were surveyed in detail; the findings are summarized in Table 3. (The data is repeated where applicable in Section 3.2 where it is compared to the overall population data).

Table 3

Summary of b Series Surveys
Test Data

Garage	Above or below grade	Number of Suspended Levels	% of Slab Area Delaminated/ Debonded in Test Areas		% Scaling in Test Areas		Corrosion Activity - Volts C.S.E. % of readings in Test Areas		Cover		Chloride Ions % by weight of concrete at top reinforcing steel (Average)	Quality of Air Void System (6)	Average Compressive Strength MPA	Water absorption % by weight	Density Kg/m^3	Chloride Permeability coulombs
			Range	Average	Range	Average	Mean	> 0.35,%	Average	Average Standard Deviation mm						
b1	below	2	14-96(1)	42(1)	52-100(2)	84(2)	0.24	14	23	13	0.247	poor	49	6.4	2385	too high to record(3)
b2	above	6	-	nil	negligible	-	0.18	Nil	43	9	0.019	good	50	4.9	2349	2675(4)
b3	above	10	-	nil	slight	-	not determined		37	10	0.042	good	32	-	-	6203
b4	below	2	-	nil	slight/ moderate(7)	-	not determined		(5)	(5)	-	-	-	-	-	-

NOTES:
- (1) Mainly debonding of concrete topping.
- (2) Scaling of concrete topping.
- (3) Chloride permeability of concrete topping.
- (4) One high possibly atypical result increased average value.
- (5) Slabs protected by 98 mm thick concrete topping and 9 mm thick waterproofing. No delamination evident.
- (6) Based on criteria of CSA A23.1-M77.
- (7) Scaling of concrete topping.

3.1.3 "(c)" Series Structures

The "c" series structures were surveyed as a start to monitoring the effectiveness of a number of repair and protection systems. The survey techniques used for monitoring are described in 2.9 "Methodology for Detailed Surveys". Assessment of the effectiveness of the repair and protection systems is given in 5.1.3. Where applicable, they are also reported in Section 3.2 where they are compared to overall population data. The monitoring data is given in Table 4.

Table 4
Summary of c Series Surveys
Test Data

Garage	Above (A) or Below (B) Grade Interior (I) or Exposed (E)	No. of Suspended Levels	Age (Years) At time of repairs	Age (Years) At time of survey	Main Structural System	Protective System Type	Chloride Permeability(1) (coulombs) Range	Chloride Permeability(1) (coulombs) Mean	Cover(2) (mm) Range	Cover(2) (mm) Mean	Cover(2) (mm) Standard Deviation	% of Slab Delaminated in Test Areas Range	% of Slab Delaminated in Test Areas Average	Corrosion Activity (-Volts C.S.E.) Range	Corrosion Activity (-Volts C.S.E.) Mean	Corrosion Activity (-Volts C.S.E.) >.35, %
c1	B I	1	10	13		W3	0-120	51	20-90	46	13	1.7-11.1	4.6	0.08-0.32	0.16	Nil
c2	B I	7	11	16	One way slab on beams	W4	Nil	Nil	25-90	50	14	0-0.5	0.2	0.01-028	0.12	Nil
c3	A I	4	20	26	On steel frame	Various	Nil	Nil	-	.(3)	-	0-29.2	17.4	0.10-0.38	0.20	2.8
c4	B I	Nil	11	13		-	-	4195(4)	-	-	-	-	-	-	-	-
c5	A E	7	7	9	One way slab on beams	W1	641-2329	1316	-	-	-	0.8-1.2	1.0	0.10-0.47	0.27	28.0
c6	A E	6	12-13	15		Sealer	2085-2890 297-1741 950-1098	2517(5) 923(6) 1020(7)	-	-	-	3.1-39.5	26.6	0.13-0.61	0.35	48.7
c7	A E	4	23	26		Asphalt	Too high to record		-	-	-	27.2-47.9	39.4	0.12-0.61	0.31	35.2
c8	B I	1	4	9		W2	Nil	Nil	-	-	-	1.2 - 2.3	1.8	0.09-0.43	0.17	1.7
c9	B I	1	2	7		W5	Nil	Nil	70-105	94	5	0-3.6	0.8	0.03-0.32	0.11	Nil
c10	B I	3	19	21	Some on steel, Some on R.C.beams	W3 on asphalt	-	-	-	-	-	-	6.6	0.08-0.28	0.16	Nil
c11	B I	1	7-8	10		Sealer (S-1)	2042-4327 60-617 1676-2063	2899(8) 404(8) 1881(9)	20-65	39	12	0-1.2	1.9	-	-	-

NOTE: (a) All structures were: Cast-in-place, Reinforced Concrete, Flat Slab Construction
Cover data from cores not included in table since it is not always clear which bars are from top and which from bottom mat.
(b) c4 structure: evaluation limited to crack repair system.

(1) Results are for 3 tests.
(2) Data from covermeter survey.
(3) Mostly debonding of concrete overlay.
(4) One test only.
(5) Original concrete.
(6) Original epoxy overlay
(7) Repair concrete.
(8) Unsealed concrete.
(9) Sealed concrete.

3.1.4 "(d)" Series Structures

All of the structures in the "d" series were above ground.

Three of the structures, d1, d3 and d10 were steel frames. In one case, d1, the concrete deck was a reinforced concrete deck supported by steel beams and, in both the other structures, a thin concrete slab on steel deck was used. The steel frames, although exhibiting rust, were in structurally sound condition. In d3 and d10, the steel pan system was in an advanced stage of deterioration and ready for replacement. Structure d9 had the lower parking level supported on steel beams which were in good condition and, although not clear from the survey, it would seem likely that this level was waterproofed under the asphalt wearing surface.

The concrete part of all these structures together with the steel pan components of d3 and d10, were rated as being in poor condition.

Structure d4 was the only post-tensioned structure in the sample and was in very good condition. Drainage was excellent and there were no cracks visible in the whole of the top surface. Expansion joints were of good quality and in good condition. There was clear evidence that the top surface had been sealed more than once.

Structure d6 was an unusual design, in that it comprised a reinforced concrete frame, with cast-in-place post- tensioned horizontal beams and a cast-in-place concrete slab. The structure was classified as being in only fair condition, there being potentially serious deterioration to both the precast post-tensioned beams and the floor slabs.

The remaining five structures in this sample were reinforced concrete frames and slabs. The three classified as good had good drainage and were from 7 to 12 years old. The two rated as only fair had good drainage. The only significant difference between these two and to the other three was their age which was 20 and 22 years respectively. In addition, d11 had a concrete overlay which presumably was providing protection to the reinforced concrete slabs.

3.1.5 "(e)" Series Structures

The twenty-two garages in the section were those classified as category one or two in the overall Ontario Housing Corporation survey. This meant that, insofar as the survey data showed, these were in almost perfect condition needing very few repairs.

Our findings are summarized in Table 5.

Table 5

Summary of e Series Data

Structure	Needed Repair	Slab on Grade	Small*	No Roof Parking	Little Use	Remarks
e1	x	-	x	-	x	
e2	-	x	-	x	-	
e3	-	x	-	x	-	
e4	-	x	-	x	-	
e5	-	x	x	x	x	
e6	x	x	-	-		
e7	-	x	-	some	-	
e8	-	x	x	x	x	
e9	-	-	x	-	x	
e10	-	x	x	-	-	
e11	-	x	-	x	-	
e12	-	x	x	-	-	Under bldg.
e13	x	-	-	x	x	
e14	-	x	x	x	-	
e15	-	x	x	x	-	
e16	x	x	x	x	-	
e17	-	x	x	x	-	
e18	-	x	x	x	-	
e19	-	x	x	some	-	
e20	-	x	x	-	x	
e21	-	-	x	-	x	
e22	-	x	x	some	-	
TOTAL	4	18	15	12/3	7	

* Less than 5,000 m^2.

It will be seen from the above tabulation that there were certain general characteristics evident in these structures. Almost all of them consisted of a slab on grade with no suspended slabs. They were generally small and no parking was allowed on most of the roofs, or only part of the roof was used in this manner.

Several of these garages required repair and e1, in fact, was in an advanced state of deterioration and should not have been classified as good in the original survey.

In six of the garages, our field notes showed that these were little used. Our information from the Corporation representatives and representatives of the Metropolitan Toronto Housing Association is that these garages usually get very little use because of the income level of the tenants, and/or restrictions in access to housing being related to car ownership.

It seems clear, therefore, that none of these structures were suitable for inclusion in our detailed surveys, but they did provide useful information with regard to the fact that the main source of problems in underground garages is suspended slabs and, where these are eliminated, a significant portion of the problem disappears. In addition, although in many garages, roofs are a source of major problems, where no parking is allowed on roofs, the problem becomes much smaller. Finally, we believe that this sample provides substantial evidence of a clear relationship, although not quantifiable, between the amount of usage and the amount and rate of deterioration.

3.1.6 "(f)" Series Structures

While the three garages in this section were reported as being in good condition, the survey data showed that they were all in poor or fair condition. On the other hand, it should be noted that their age was between 19 and 22 years and, although all required major rehabilitation, they had remained serviceable for two decades.

Since none were waterproofed, it is assumed that the only difference between these and more recently built underground parking structures was that their design predated ultimate strength design criteria. In the 1981 study for CMHC(22) of 84 garages it had been found that those which pre-dated the use of ultimate strength design had proved to be more durable than those built afterwards.

Therefore, although none of these structures proved to be durable, in the sense that they had deteriorated significantly, they had all given twenty years of service prior to needing extensive rehabilitation. Also, some repairs had been made in the structure which was in the best condition of the three.

3.2 Project Survey Data Compared to Overall Garage Population Data

In this section the findings from the study sample are reviewed and compared to date obtained from the overall Trow data base. This enables the study data to be compared to norms derived from a large data base.

3.2.1 Cracking

3.2.1.1 General

Reinforced concrete is designed to crack. The change from working stress design to ultimate, or limit-state design, about 1970, led to the use of less reinforcement in slabs. Wider cracks resulted.

In his paper on Cracking, Cover and Corrosion of Reinforcement, (36) Beeby concludes that crack widths had little influence on corrosion and that major parameters controlling corrosion are cover thickness and concrete quality.

Illustrations are given on the minimum cover thickness and design crack widths allowed or required by the codes in a variety of countries. Cover thickness, for worst exposure conditions, ranges from 20 mm in Austria to 60 mm in England, with the average, for the thirteen codes quoted by Beeby of 35 mm. ACI and CSA codes specify 50 mm.

Design crack widths, calculated using a variety of international regulations gave values from less than 0.1 mm to more than 0.3 mm, with ACI and CSA values just over 0.2 mm.

Beeby concludes that, while all countries appear to agree on the parameters which control durability, there are enormous differences between countries over what would actually constitute a durable structure.

He concludes, therefore, that the interaction between environment, cover, mix proportions, crack widths, and corrosion is not generally understood.

At a debate at the American Concrete Institute Convention in New York in November 1984 it was concluded that chloride permeation to the reinforcing steel occurs so quickly that any effects due to cracking would be irrelevant.

In a concrete highly impermeable to chloride ion intrusion wide cracks might have a significant effect on the rate of corrosion.

For condition surveys, there are a number of criteria for the classification of crack widths, as follows:

National Cooperative Highway Research Programme, Synthesis of Highway Practice 57 entitled "Durability of Concrete Bridge Decks" (3)

Hairline - less than 0.1 mm
Narrow - 0.1 to 0.3 mm
Medium - 0.3 to 0.7 mm
Wide - greater than 0.7 mm

Ontario Ministry of Transportation and Communications

Narrow - 0.3 mm
Medium - 0.3 mm to 1 mm
Wide - 1 mm

ACI 210.1R-4 "Guide For Making A Condition Survey of Concrete In Service"

Fine - 1 mm

Medium - 1 to 2 mm

Wide - 2 mm

These criteria were not used in the project surveys but are presented for information.

3.2.1.2 Incidence of Cracking

Two sets of criteria are available in the literature for objectively assessing the incidence of cracking. These are:

Canada Housing and Mortgage Corporation Report entitled "Nature, Extent, And Impact of Residential Parking Structure Deterioration" (22)

Few	-F-	1 m per 20 m^2
Numerous	-N-	1 m per 4 m^2

Ontario Structure Inventory System, Ministry of Transportation and Communications

Very Few	-VF-	1 m per 100 m^2
Few	-F-	1 m per 10 m^2
Numerous	-N-	1 m per m^2
Very Numerous	-V-N	1 m per 0.1 m^2

The cracking data obtained on the fifteen projects surveyed in series "b" and "c", for this research program were analysed to determine the amount of cracking present in each structure. This was determined by an underside visual survey of the suspended slabs.

The data are summarized in the following table.

Table 6

Incidence of Cracking

Project	m^2 of deck per m of cracks	Incidence of Cracking CMHC Criteria	Incidence of Cracking MTC Criteria
b1	10.2	F	F
2	166.7	F	VF
3	76.9	F	F
4	43.4	F	F
c1	15.6	F-N	F
2	9.4	F-N	F-N
3	14.9	F-N	F
4	43.5	F	F
5	500.0	F	VF
6	40.0	F	F
7	13.5	F-N	F
8	10.1	F-N	F
9	14.3	F-N	F
10	16.7	F-N	F
11	4.3	N	F-N

VF	Very Few
F	Few
N	Numerous

It will be seen from the summary of the data that the incidence of cracking in these structures was shown to be less when determined by an objective criteria than would generally be assessed by a subjective visual assessment. This may call into question the validity of the criteria used. On reflection, however, they are considered to be reasonable. It is therefore concluded that parking decks are not as badly cracked as has been commonly supposed.

An overall assessment of the significance of cracking in a particular structure will require data on crack width and the evaluation of the structural significance of any major cracks or crack patterns.

3.2.2 Scaling

Scaling is defined as the local flaking or peeling away of the near-surface portion of hardened concrete.

Two sets of criteria for assessing the severity of scaling are found in the literature:

Ontario MTC and NCHRP 57 (3)

Light Scaling:	0 - 5 mm
Medium Scaling:	5 - 10 mm
Heavy Scaling:	10 - 25 mm
Severe Scaling:	over 25 mm

ACI 201

Light Scaling:	loss of surface without exposure of coarse aggregate
Medium Scaling:	5 to 10 mm.

Scaling was not severe nor was it a significant factor in the overall condition of any of the structures surveyed in this study, although it was extensive in one structure (b1). No quantitative assessment of it was made, therefore.

3.2.3 Delamination

3.2.3.1 General

The removal and replacement of delaminated concrete is normally the most expensive cost item in a repair programme.

3.2.3.2 Increase With Time

It is well known that delaminations increase with time but not quite so well known is the fact that the rate of increase is highly variable. Factors affecting the rate of increase have not been quantitatively determined, but there is already broad agreement that usage, cover thickness, humidity, temperature, and concrete quality are factors. This increase in the amount of damage with time has an effect on repair costs, which may escalate significantly if repairs are delayed.

Little data is available on the increase in the amount of deterioration of a parking structure with time. This is because, in practice, structures are normally repaired shortly after the condition survey has been made. Typically, a survey will not be made until an owner realizes that there is a need for rehabilitation.

On a number of occasions however, because of delays to the rehabilitation of the whole or parts of structures, Trow have resurveyed areas at intervals.

On one project, subject to investigation and repair over a period of four years, a number of areas were resurveyed. For six parking decks involving the delamination survey of over 10,000 m^2 of test areas, the average increase in delamination over a period of three years, was to 247 % of the original amount, i.e. from an average of 4.7 % deck delaminated to an average of 11.6 % of the test areas. The range of increase varied from 137 % to 491 %. On the same project, for two steeply sloping ramps, the increase in three years was nil for one ramp and from 0.2 to 8.1 % delaminated concrete for the other.

The test data for the six parking deck areas are summarized below.

Table 7

Delamination Increase Data

Test Area	% Delaminated At Age 6 Years	At Age 9 Years
1	7.3	10.0
2	3.5	17.2
3	4.6	12.4
4	6.4	17.7
5	3.5	8.3
6	2.0	4.0

In four other test areas in flat slabs in the same project tested three times the average percent increase after 1 1/2 years was 132 % (with a range of 52% to 352 %) and after a further year was an additional 17 % (with a range of 3 % to 70 %). The actual values obtained are tabulated below.

Table 8

Delamination Increase Data

Test Area	Increase In The Area Of Delaminated Concrete Compared To The Amount In The Original Survey % Of Total Area After 1 1/2 Years	After 2 1/2 Years
1	88	91
2	52	58
3	352	422
4	107	117

As will be seen, there was no consistency in the rate of increase.

On another project, a steeply sloped interior ramp was monitored for four years before repair. The following is a summary of the data.

Table 9

Delamination Increase Data

	% Delaminated	Increase as a % of Original
Initial Test	1.2	---
1 1/2 years later	3.3	275
2 1/2 years later	8.0	667
3 1/2 years later	14.6	1217

As will be seen for three years the amount of delamination virtually doubled each year!

The increases detailed above are shown graphically in Figure 3.

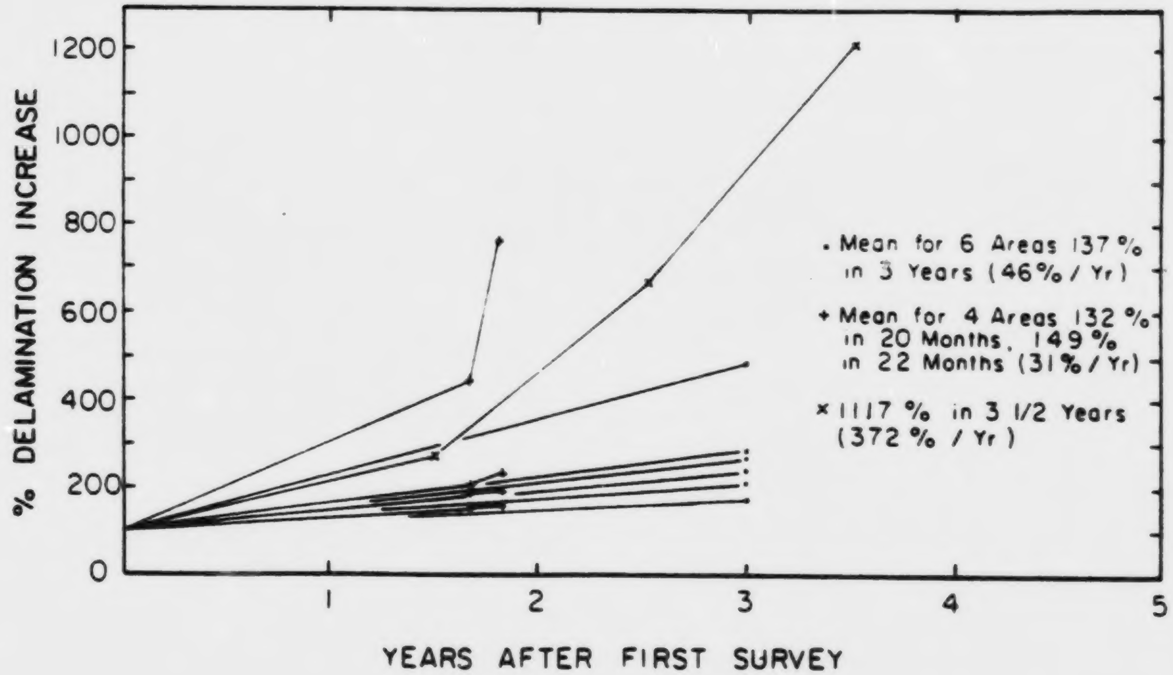


FIG. 3 DELAMINATION INCREASE WITH TIME

It is perhaps misleading to express the growth of delamination as a percentage increase compared to the amount found at the time of initial survey. Clearly no delamination occurs in the early life of a structure. Until chloride penetration to the steel has occurred and corrosion has started no damage results. The time to reach this condition will vary from structure to structure and within a structure. If the initial delamination survey coincides with an early stage of the delamination, subsequent surveys may show large percentage increases. Once started the growth of delamination may accelerate and indeed be exponential until all areas containing top steel have delaminated. Similarly if at the time of the initial survey a significant percentage of the slab area containing top steel has already delaminated percentage increases in subsequent surveys will presumably appear smaller.

Fig. 4 shows all data available to Trow, including that given above. It shows the actual delamination, expressed as a percentage of the total area of the slabs, and showing its relationship to the age of the structure.

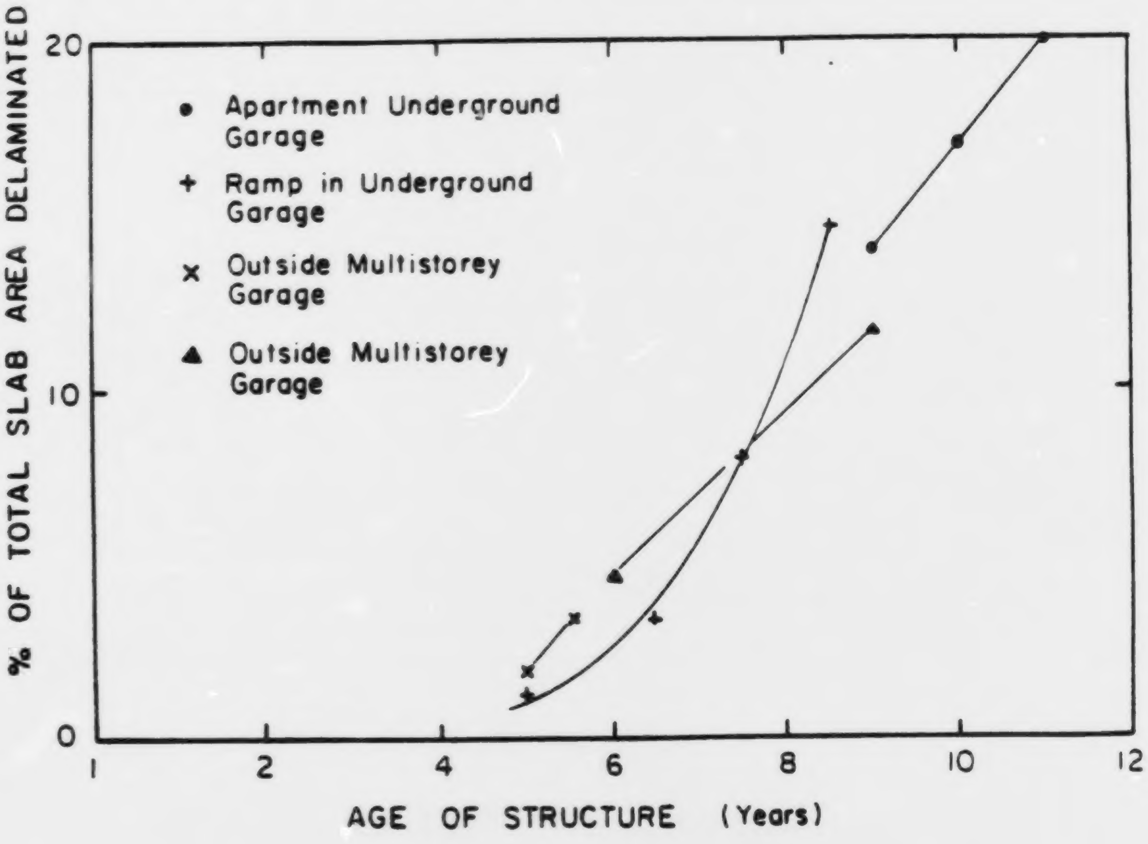


FIG. 4 DELAMINATION GROWTH WITH TIME

MTC practice is to add 10 to 25 % to the amount of delaminations determined in a survey if repairs are delayed one year.

3.2.3.3 Typical Data

An analysis of data, obtained on 69 surveys carried out by Trow independent of the project sample, showed that the an average amount of slab delamination per structure, at the time the condition survey was made, and not co-related to age, of the building, was 13.1 % of the total suspended parking deck area, with a range of 0 to 47.6 %. Delamination percentages ranged as high as 70 % for individual levels. These data are shown graphically in Figure 5.

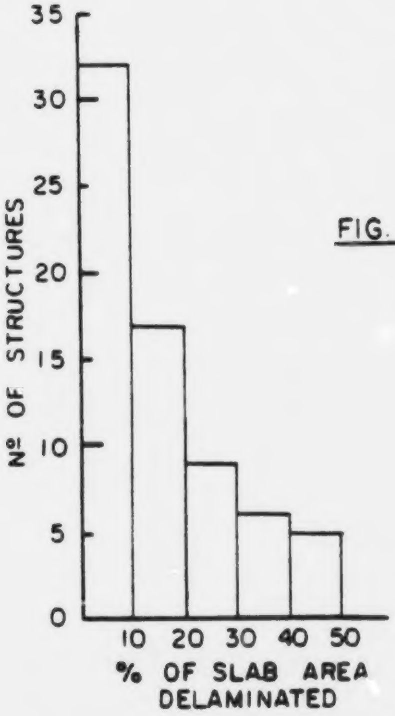


FIG. 5 AMOUNT OF SLAB DELAMINATION AT TIME OF CONDITION SURVEY (69 STRUCTURES)

For 41 structures surveyed by Trow, independent of this project, sample data was available for both age and amount of delamination. When the amount of delamination at the time of the survey was compared to the age of the structure, using linear regression, a correlation coefficient of 0.4 resulted, showing negligible correlation.

Of separate interest is the age of 46 structures at the time at which those were surveyed. This age can be accepted as the time by which significant deterioration was apparent. These data are shown in Figure 6.

In most slabs, since delamination of the top surface only occurs where there is top steel, only a proportion of the total area can delaminate. No attempt has been made to adjust the data to reflect this proportion, which would, of course, vary from garage to garage.

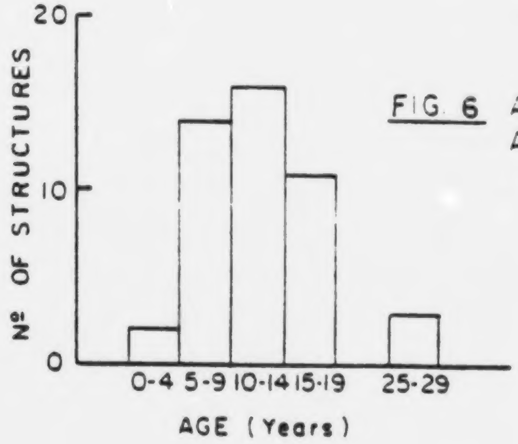


FIG. 6 AGE OF STRUCTURE AT TIME OF SURVEY OF 46 STRUCTURES

The data in Figures 5 and 6 represents the damage present at the age at which the owners perceived that a survey was necessary.

3.2.3.4 Study Data

The amount of slab delamination in the project study structures, where determined, was as follows:

Table 10

Project Data on Delamination

Structure	Age (years)	Time Since Repaired (Years)	Area % of Slabs Delaminated
b2	11	N.A.	0.1
b3	5	N.A.	Nil
c1	13	3	4.6
c2	16	5	0.5
c4	13	2	1.0
c6	15	2-3	26.6
c7	26	3	39.4
c8	9	5	1.8
c9	7	5	0.9
c10	21	2	6.6
c11	10	2-3	7.3

3.2.3.5 Accuracy of Chain Drag

No definitive data is available now to show the accuracy or repeatability of the chain drag test. However, Manning expressed the opinion (30) that it is the most accurate test available.

3.2.4 Cover

3.2.4.1 Typical Data

In surveying parking structures, it has been commonly noted that not only is concrete cover frequently inadequate, but there is very wide variation in the amount of cover, varying from 0 to 100 mm or more. In 1976, The Ministry of Transportation and Communications of Ontario carried out a survey, to determine to what extent reinforcement placing resulted in cover complying with their requirements. The results were reported in Durable Highway Structures -Recent Developments in Ontario by Ryell, Owens and Manning, published in September 1982. This showed that compliance with their specification varied between 18 and 100 percent.

Where statistical analyses are made of the variations in concrete cover it has been found that a diligent bridge contractor will produce a standard deviation of 10 mm, assuming an acceptance criteria of not more than 2.5 % of the measurements being less than the specified minimum cover.

With regard to practice in the design and specification of parking structures, it has been almost universal to specify minimum cover of 19 mm, with a small proportion of Engineers increasing this to 25 mm. It is clear, therefore, that, until recently, very few Engineers interpreted interior parking structure slabs as being in a hostile environment.

Furthermore, it is clear that, in the typically thin slabs used in most parking structures, there was no consideration of the effect of acceptable tolerances for the placing of reinforcement; on the thickness of the slab, if high degrees of compliance with minimum cover requirements were to be achieved.

The achievement of 95 % compliance with minimum cover requirements would mean that 95 % of the bars would have to be within the range of the average cover of ± 1.96 standard deviations. This would therefore mean that where 19 mm was specified as minimum cover, the actual minimum cover for placing would have to be 39 mm, assuming a diligent contractor achieving a standard deviation of 10 mm. This would be a significant increase in the thickness of a slab, purely from the point of view of achieving minimum cover requirements.

In the following table are summarized the measurements obtained by Trow Ltd. in surveying 36 garages not included in this project sample. Each survey involved several test areas, and the data for each garage is an analysis of all the readings obtained for all the test areas. For each garage, therefore, the data will often relate to more than one level.

Table 11

Cover Summary

No.	No. of Readings	Range (mm)		Mean (mm)	Standard Deviation (mm)
		Min.	Max.		
7.	220	15	90	52	24
14.	313	5	65	58	11
14.	588	0	75	33	12
14.	1014	0	65	31	12
15.	219	3	115	49	27
16.	379	28	105	64	13
16.	545	20	70	43	10
17.	22	0	100	51	24
18.	104	3	75	39	14
20.	127	23	75	48	12
21.	68	20	90	41	19
22.	272	25	70	48	11
27.	207	5	65	30	10
30.	81	10	50	28	12
32.	100	10	65	37	10
36.	277	0	95	46	19
45.	581	0	90	41	14
46.	83	15	65	38	10
49.	436	15	90	45	14
51.	321	0	70	39	13
52.	456	20	115	51	23
54.	43	20	60	36	10
56.	40	20	60	36	13
60.	93	15	90	45	12
74.	96	0	85	43	16
87.	78	3	80	36	19
88.	82	15	65	35	12
97.	275	10	85	43	17
102.	74	15	70	31	12
109.	22	20	65	42	10
125.	51	0	75	36	15
142.	110	20	70	38	10
143.	156	0	75	36	15
161.	136	25	90	51	14
172.	164	15	95	46	18
179.	167	10	85	46	15
TOTAL	8000				
MEAN		0	115	42.4	14.3

The average cover found in the above 36 surveys is shown graphically in Figure 7.

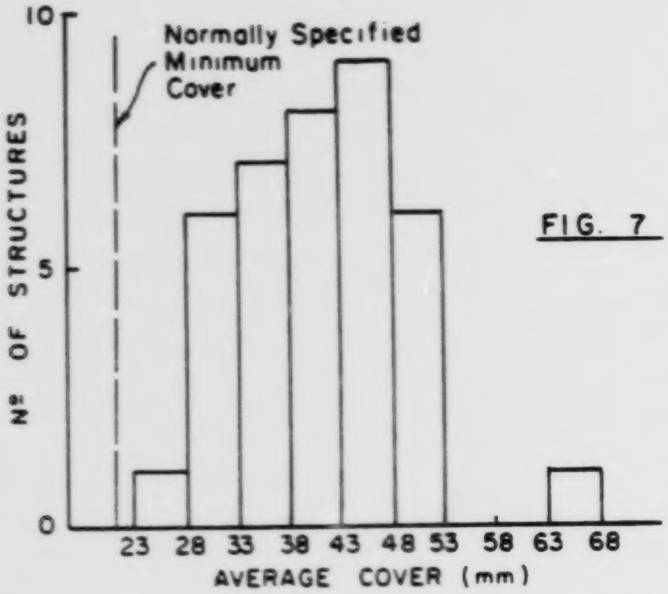


FIG. 7 AVERAGE COVER (36 SURVEYS)

As stated above, it has been determined by the MTC, that a diligent contractor will place reinforcement to an accuracy characterized by a standard deviation of 10 mm. It should be noted that bridge decks are generally relatively small in area compared to parking structures and, further, the lanes on one side of the central median are normally treated as a separate deck. In a parking structure, there are many levels, quite frequently with many different slopes, and also columns, shear walls, elevator shafts and re-entrant corners. It would, therefore seem reasonable to assume that it is more difficult to consistently achieve a good standard of reinforcement placement in such a structure.

If the data given in Table 11 is examined it will be seen that, of the total number of surveys for which covermeter work is reported, 29 out of 36, or 81 % of the sample show a mean standard deviation greater than 10 mm. 7 or 19 % show a mean standard deviation of 10 mm. These data are shown graphically in Figure 8.

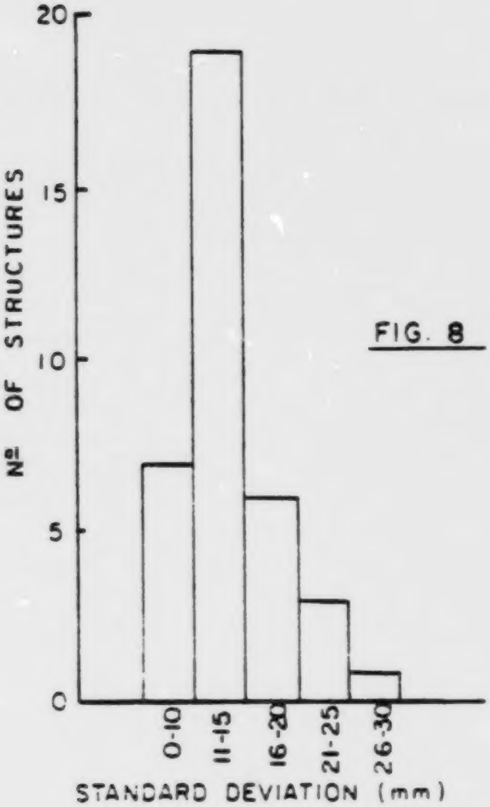


FIG. 8 VARIABILITY OF COVER

In the 36 condition surveys from which data is available the total number of test areas involved was 266. 71 of these or 31 % of the sample had a mean standard deviation that was equal to or greater than the mean standard deviation for the structure in question. It would therefore appear to be fairer to judge the standard of placing of reinforcement in a parking structure on the results for each single test areas, or perhaps for a single level.

In 86 of the test areas or 38 % of the sample, the standard deviation was less than 10 mm. It is clear therefore that, even when judged on the most favourable criteria, only 38 % of all the areas tested met the MTC Standards for diligence. It is therefore clear that the average standard of reinforcement placing in a parking structure falls short of the criteria applied by the MTC.

In the paper "How Accurately Can Reinforcing Steel be Placed?" (47) Morgan and others concluded that for top reinforcement, the position of an individual bar could be specified to be within ± 13 mm. This is a considerably tighter requirement than that which would meet the standard given by MTC of a standard deviation of 10 mm. The latter would mean that 95 % of all results would fall within a range of ± 20 mm of the specified cover which is more than 50 % greater tolerance than that given in the paper quoted.

3.2.4.2 Study Data

Table 12

Project Data on Cover

Structure	Average Cover mm	Range mm	Standard Deviation mm
b1	23	0 - 55	13
b2	43	20 - 70	9
b3	37	15 - 80	10
c1	46	20 - 90	13
c2	50	25 - 90	14
c9	94	70 - 105	5

3.2.4.3 Accuracy of Covermeters (Pachometers)

An accuracy of ± 3 mm for cover up to about 40 mm and ± 5 mm for cover more than 40 mm is required and is provided by most commercial pachometers. These instruments need frequent calibration and such a procedure must be part of the daily routine if reliable results are to be obtained. British Standard BS 4408: Part 1: 1969, "Recommendations for Non-Destructive Methods of Test for Concrete, Part 1 Electro-Magnetic Cover Measuring Devices" gives guidance in the calibration and use of these instruments.

Average cover determined from core logs from 58 surveys is shown in Figure 9.

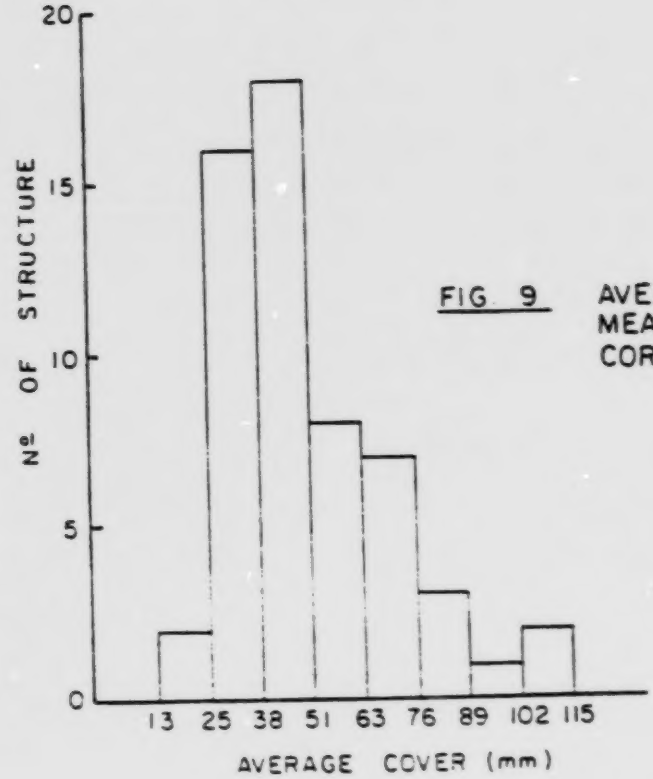


FIG. 9 AVERAGE COVER MEASURED FROM CORES

Average cover found was 50 mm.

3.2.5 Chloride Content

3.2.5.1 Calcium Chloride

In "Synthesis of Highway Practice 57",(3) Manning shows how a value of chloride ions of 0.025 % by weight of concrete can be calculated into quantities of either sodium chloride or calcium chloride in the concrete. In the example given, it is shown that a 0.025 % chloride ion content, in a concrete containing 390 kg of cement per m^3 would be achieved by the addition of about 1.25 kg of calcium chloride per m^3 of concrete. This clearly represents only about 0.3 % by weight of cement in terms of commercial calcium chloride addition. As shown by the review of construction codes and standards in Canada, it is still permissible to add as much as 2 % by weight commercial calcium chloride to concrete. In this event, in the case of a typical bridge deck concrete, the quantity would be as high as 7.8 kg of calcium chloride per m^3 and this would result in a chloride ion content of approximately 0.16 %, or more than six times the threshold value for the onset of corrosion (3). Similarly, if a typical, commercial guaranteed strength, 20 MPa, mix is considered (in which the cement content per cubic yard is approximately 250 kg of cement per m^3), the addition of 2 % by weight of commercial calcium chloride will result in a chloride ion content of approximately 0.2 % by weight of the concrete, or approximately eight times the threshold value. While a significant proportion of the added calcium chloride may (or may not) be available to affect corrosion, clearly there is grave danger, from a corrosion point of view, in adding what are, in terms of threshold values, enormous amounts of chloride ions.

3.2.5.2 Typical Data

An analysis of 136 test results, for 62 garages investigated, gave a mean value of 0.155 % * chloride ions by weight of concrete, in levels down to the top reinforcing steel. The standard deviation was 0.154 %, with a range of 0.003 to 0.732 %. None of these values were corrected for background chlorides. It is interesting to note that the mean is twice that found in bridge decks in North America. (51)

The distribution of chloride ion contents in shown in Figure 10.

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* The source of these chlorides was not determined.

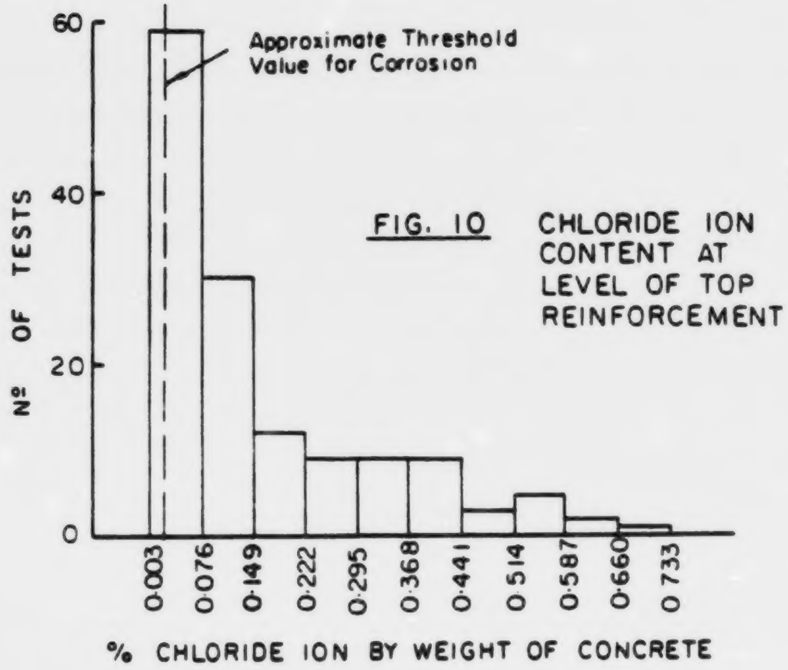

FIG. 10 CHLORIDE ION CONTENT AT LEVEL OF TOP REINFORCEMENT

3.2.5.3 Study Data

Table 13

Project Data on Chloride Content

Structure	% Chloride Ion
b1	0.206, 0.152, 0.382
b2	0.006, 0.008, 0.043
b3	0.047, 0.107, 0.010,0.005

3.2.6 Corrosion Activity

3.2.6.1 Typical Data

A summary of corrosion activity, as determined by the half-cell test, found in 61 structures surveyed by Trow independent of the project sample, is shown in Figure 11.

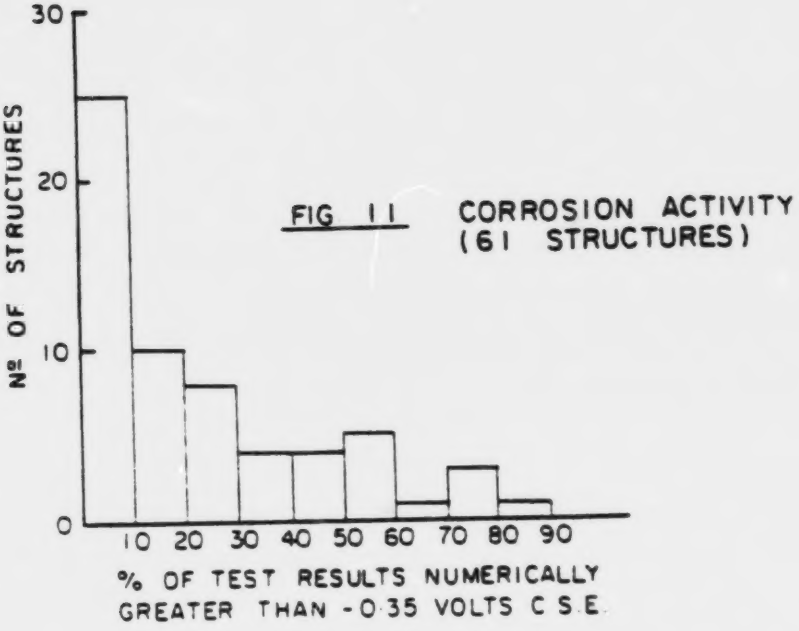
FIG 11 CORROSION ACTIVITY (61 STRUCTURES)

Average % greater than 0.35 volts was 23.7% and the range was nil to 82.9%.

3.2.6.2 Study Data

Table 14

Project Data on Corrosion Activity

Structure	Half-Cell Readings Volts C.S.E. Mean	Range	% > 0.35
b1	0.24	0.02 - 0.54	14.0
b2	0.18	0.02 - 0.27	Nil
c1	0.16	0.08 - 0.32	Nil
c2	0.12	0.01 - 0.28	Nil
c3	0.20	0.10 - 0.38	2.8
c5	0.27	0.10 - 0.47	28.0
c6	0.35	0.13 - 0.61	48.7
c7	0.31	0.12 - 0.61	35.2
c8	0.17	0.09 - 0.43	1.7
c9	0.11	0.03 - 0.32	Nil
c10	0.16	0.08 - 0.28	Nil

3.2.7 Compressive Strength

3.2.7.1 Typical Data

While inadequate compressive strength is seldom a problem, it is normal practice to check this feature as part of the condition survey of a structure. The common and most satisfactory test method is the drilling and testing of cores, a procedure first covered by an ASTM standard procedure in 1921.

A summary of compressive strength data obtained on sixty projects surveyed by Trow independent of the project sample is as follows:

		MPa
Range	-	27.3 to 57.3
Mean Strength $(\overline{\chi})$	-	40.3
Standard Deviation (σ)		6.75

Applying the 85 % correction factor allowed by CSA for converting core strength to equivalent standard cylinder strength the latter equivalents would be as follows:-

		MPa
Range	-	32.1 - 67.4
Mean Strength $(\overline{\chi})$	-	47.4

These are high strengths. They are also higher then might be expected but the advanced age of the concrete would be a factor. Also, cement strengths in the last two decades have been signficantly higher than required by standards.

A plot of these data, against the age of the structure, (where known) showed no correlation.

3.2.7.2 Study Data

Table 15

Project Data on Compressive Strength

Structure	Compressive Strength, MPa	
	Individual Results	Average
b1	47.8, 53.8, 46.3	49.3
b2	49.9	49.9
b3	28.1, 31.3, 36.7	32.0

3.2.7.3 Strength and Quality

No valid relationship between age and strength of concrete exists. However strength has never been found to be a problem, in itself, in any condition surveys made. It is also clear from the data that, while strength was generally always satisfactory, the quality of the concrete was not.

Typically, a high percentage of such structures were built with concrete supplied, in major urban areas, to a guaranteed strength specification, the proportioning being left to the supplier. The most common strength specified was 21 MPa, followed by 25 and 30 MPa. For 21 MPa concrete typical mixes have historically contained as little as 230 kg of cement per m^3. For a mix of 230 kg of cement per m^3, a typical stated total water content of 149 kg would give a water-cement ratio of 0.65. It is well known that in practice, particularly on many privately constructed projects, actual water contents were often significantly higher.

Based on the most recent chloride permeability data, which is summarised in Table 16, it is clear that such older concretes would be very permeable and would have high coefficients of drying shrinkage.

Specifying compressive strength, therefore, would not appear to be a satisfactory way of obtaining the desirable quality of concrete in a parking deck to ensure durability.

3.2.8 Chloride Permeability

Concrete is not in itself sufficiently impermeable to provide protection to reinforcement by excluding the ingress of chloride ions. Permeability measures this quality of protection.

While the rapid chloride permeability test would appear to offer a rational way of testing the effectiveness of protective coatings, whether waterproofing systems or sealers or overlays, there is lacking an extensive body of evidence which shows whether or not the standard procedure as developed by Whiting (53), is suitable in all cases. It has been suggested, by Clear*, that the test should be modified when testing a sealer, so that, instead of using vacuum saturation, the test specimens are only partially saturated with water. The problem here would appear to be achieving some uniformity of saturation and conductivity. On the other hand, it appears that, from some limited work carried out by Clear *, there is a reasonable correlation between the modified ponding tests and the modified rapid chloride permeability test which he has devised.

It is suggested that, perhaps, the rapid permeability test may not function in the same way where the concrete specimen is removed from chloride saturated concrete which has been in service for some time. The very presence of significant quantities of chloride ions in the vacuum saturated specimen prior to the start of test, may well affect the conductivity, and therefore the numerical values obtained when additional chloride ions are electrically forced through the protective system. Further research should be done in this field.

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* Private communication.

It should be noted that, in the definitive publication by Transportation Research Board Publication No. 244 on the Performance of Sealers,(26) it is stated very clearly that these materials are for use on horizontal surfaces. It should also be noted that, in his test reports on sealers, Clear states that they are not for use on abraded surfaces. It would therefore seem that the whole technology of the evaluation of sealers, for use on abraded surfaces, has yet to be developed. Unless such materials work on abraded surfaces, and parking decks are certainly abraded, and unless a suitable technology for evaluation is proven, it will not be possible to accurately evaluate the effectiveness of such materials in advance, nor to determine by monitoring surveys the extent to which they have proved effective.

In addition to the data obtained in this study, typical results produced by Trow in recent testing are given in Table 16. These data are presented here because very little information has been published elsewhere.

Except where noted, results are for two or three test specimens, with this project study test results being shown in bold print. The significance of the following data are discussed in Section 5.

Table 16

Rapid Chloride Permeability
Test Data

Laboratory Cast Specimens

Water-cement ratio	Type of Concrete	Total Charge Passed in Coulombs		
		Mean $\bar{x}$	Standard Deviation σ	Coefficient of Variation V %
0.68	Plain concrete, Normal Portland Cement	5556	308	6
0.40	Plain concrete Normal Portland Cement	2934	654	22
0.69	Plain concrete Normal Portland Cement plus blast furnace slag and silica fume.	1053	209	20
0.40	Plain concrete, Normal Portland Cement plus blast furnace slag.	682	37	5
0.36	Plain concrete, Normal Portland Cement plus slag plus silica fume.	135	22	16
0.43#	Latex modified Overlay 25 mm thick			
	a) After 90 days ponding with 3% Na CL.	645 x 732 x 6 x #	--- --- ---	-- -- --
	b) Without ponding	690	---	--
----	Samples taken from top and bottom of 30 MPa concrete test beam.			
	a) Top	2058	240	12
	b) Bottom	1653	152	9

# Overlay debonded prior to test.
x Individual results.

Samples from Structures In Service

	Type of Concrete	Total Charge Passed in Coulombs Mean $\bar{x}$	Standard Deviation σ	Coefficient of Variation V %	Project Reference
a)	Mass concrete dam, slag aggregate 60 years old.	12777	1062	8	
b)	Unreinforced mine shaft walls, good quality, 30 years old.	888 2010	644 1058	73 53	
c)	Post-tensioned parking structures.				
	Normal weight concrete				
	i)	1443	854	59	
	ii)	2685	2008	75	
	Lightweight concrete	1542 2433 2225	53 211 251	3 9 11	
d)	Reinforced concrete parking structure slabs. Normal weight.				
	8 years old	**Permeability too high to record.**			**b1**
	15 years old	**2517**	**406**	**16**	**c6**
	Rental Property A 10 years old	9116 (2 out of 3 tests terminated before 360 minutes).	4269	47	
	5 years old	**6202**	**528**	**9**	**b3**

e) Waterproofing Systems

Project	Type	Age at Test (years)	Mean	Standard Deviation	Coefficient of Variation	Project Reference
	—	**6-11**	**Nil**	**—**	**—**	**c3**
	W-4	**6**	**Nil**	**—**	**—**	**c2**
	W-3	**4**	**51**	**—**	**—**	**c1**
New Structure	W-6	New	Nil	---	---	
	—	**3**	**922**	**741**	**80**	**c6**
	W-2	**6**	**Nil**	**Nil**	**—**	**c8**
	W-5	**6**	**Nil**	**Nil**	**—**	**c9**

		Type	Age at Test (years)	Total Charge Passed in Coulombs			
				Mean $\bar{x}$	Standard Deviation σ	Coefficient of Variation V %	Project Reference
f)	Asphalt						
	Highway overlay			Nil	---	---	
		—	4	6321	637	10	c7
g)	Concrete Overlays						
		W-1	1	1315	893	68	c5
		—	3	1020	74	7	c6
h)	Sealers						
	Normal weight post-tensioned decks.	Modified polyester resin	4 Sealer	615	321	52	
			No Sealer	1443	853	59	
	Rental property A	Concrete 10 years old Sealer New		7732	2963	38	
	Rental property B	Concrete 10 years old Sealer New		8715	4570	52	
		Concrete (1)		403	301	75	c11
		Concrete (2)		2895	1243	43	
		Sealer (3)		1880	196	10	

NOTES: (1) Dense high quality concrete.
(2) Deeply carbonated concrete with possible evidence of alkali-aggregate reactivity.
(3) Appeared to be similar to (1).

Plots of some typical rapid chloride permeability test results are shown in Fig. 12 and 13.

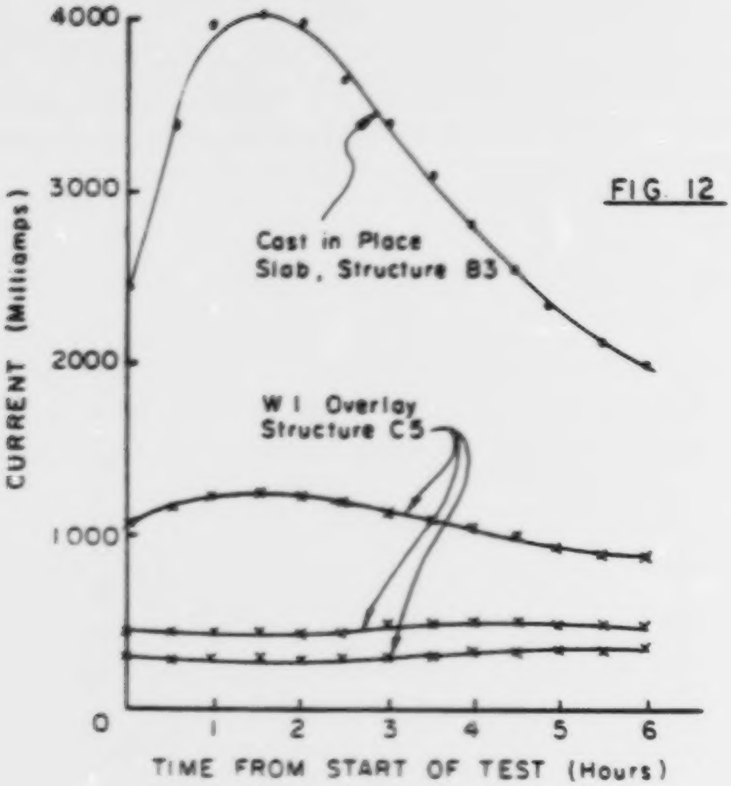

FIG. 12 RAPID CHLORIDE PERMEABILITY TEST: CURRENT V TIME

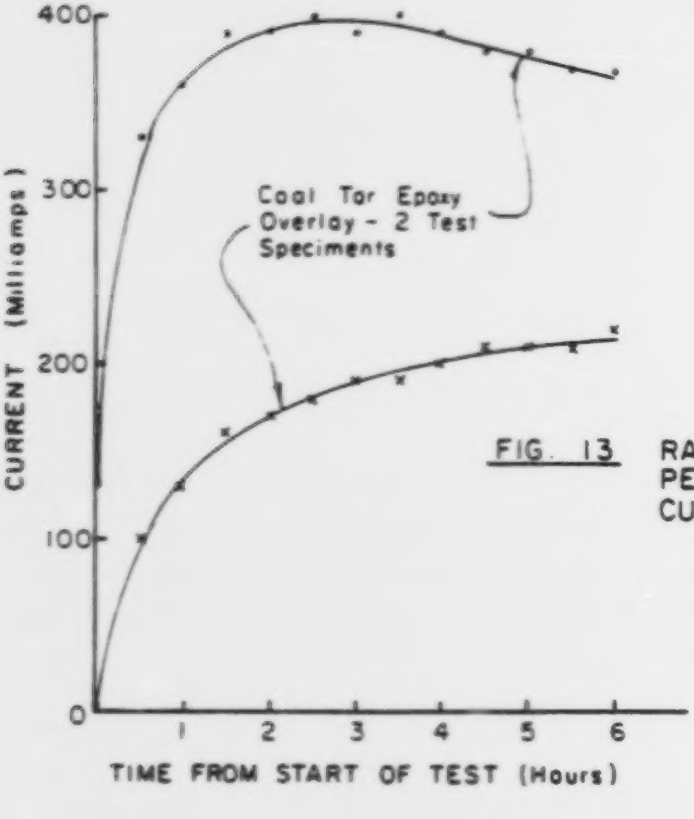

FIG. 13 RAPID CHLORIDE PERMEABILITY TEST CURRENT V TIME

3.2.9 Waterproofing

With regard to the 1981 CMHC survey(22) the following was found.

For the 31 structures which contained underground suspended slabs, 26 (or 84 %) were not waterproofed. Of the 69 structures which contained a structural slab at ground level, 54 had this roof structure waterproofed while 15 did not.

Reviewing private survey data, a total of 126 structures contained information on whether or not there was waterproofing present and in, 103 of these structure surveys, no form of protection was found.

With regard to the remaining 23 structures which showed some form of waterproofing 13 were for institutional owners, 1 was an expensive condominium, 3 were shopping centres, 3 were owned by the developer/builder, and only 3 were typical residential apartment building structures, built for sale by the original builder.

Waterproofing has therefore clearly been an exception in the past, and where used was mainly on institutional or higher priced projects.

3.2.10 Air Entrainment

3.2.10.1 Typical Data

In 129 surveys, air entrainment was found in only 3 projects. In all 3 instances the structures were external structures and should have, of course, contained air entrained concrete to meet code requirements. Of the 3 found to have air entrainment, 2 were noted as having poor air-void systems and showed evidence of freeze-thaw damage.

In 26 of these inspections there was positive evidence that there was no air entrainment and in 101 inspections there was no information either way although it is assumed that all or virtually all of these would not be air-entrained concrete because they were not required by the code to be air entrained.

3.2.10.2 Study Data

In this study, test data on air-entrainment was as follows. All sets of data comprised three tests.

Table 17

Project Data on Air Void Systems

	Air Content %		Specific Surface mm^{-1}		Spacing Factor mm	
	Range	Mean	Range	Mean	Range	Mean
Exterior Structures						
b2	7.5 - 8.6	8.2	13.2 - 17.6	15.3	0.11 - 0.19	0.16
b3	6.7 - 9.5	7.9	14.9 - 17.5	15.7	0.12 - 0.22	0.16
Interior Structures						
b1 Structural Slab	2.4 - 4.2	3.1	4 - 9	6	0.51 - 1.78	1.19
b1 Concrete Overlay	1.9 - 3.0	2.6	8 - 9	9	0.76 - 1.02	0.85

3.2.11 Expansion Joints

3.2.11.1 Typical Data

Of all the structures surveyed in the 1981 C.M.H.C. survey(22), 69 % contained defective expansion joints.

3.2.11.2 Study Data

Table 18
Project Data on Expansion Joints

Structure	Age (Years)	Leakage and/or Defects
b1	8	Some
b2	11	Slight
b3	5	No expansion joints
b4	20	Some
c1	13	Good condition
c2	16	No expansion joints
c3	26	No expansion joints
c4	13	Not noted
c5	9	Not noted
c6	15	Poor condition #
c7	26	Some
c8	9	Many
c9	7	One leak only
c10	21	Some
c11	10	Good condition

In view of the extensive ongoing deterioration in this structure the poor condition of the expansion joints may have been a factor.

3.3 Summary Statement

The significance, of the independent sets of data presented above are discussed in Section 5.

4.0 REPAIR AND MAINTENANCE

4.1 Repair Strategy

Prior to any repair or restoration program being designed it is essential to carry out a condition survey. This will determine the types and extent of damage so that these can be quantified in contract documents. The key to competitive and realistic prices for repair contracts is the production of documents providing accurate quantities and technical descriptions of the work to be done.

Subsequent to this a structural assessment should be made to determine if any of the rehabilitation is structural in nature. Damage affecting the structural integrity of the structural requires input by a Structural Engineer. Shoring and underpinning requirements will need to be identified. Sometimes limitations have to be imposed on the extent of concrete removal at one time, and also on the sequence of removal from area to area and floor to floor.

The intent of the repair and restoration program must be clearly defined otherwise it cannot be effectively developed and executed. It is helpful at this stage to develop a statement which describes exactly the intent and purpose of the forthcoming rehabilitation program. In determining the repair strategy it is necessary to look at all the alternatives. It should be determined how long the owner requires the structure should be kept in service, what funds are available, what procedures, methods and systems are available, and whether or not the structure will be exposed to unusual conditions in its future service life.

It has not in the past been easy to determine the most suitable materials and even today there is not adequate information available to enable a cost effective choice to be made based on life cycle costs and performance. The most suitable and compatible materials should be chosen therefore based on the repair team's experience.

In developing the overall repair strategy it is necessary to determine priorities. While it is desirable and often cost-effective to repair all damage as soon as possible a total cost may be beyond the budget for one year. It is often possible and desirable for a multi-year budget to be determined based on priorities, starting with the correction of most urgent priorities first.

Insofar as the present study is concerned, the repair systems which were monitored were either those which are in common use by the sponsoring departments or which were thought by the researcher to be of specific interest for future use.

An interim guideline to repair procedures has been prepared by the Ontario Chapter of ACI.(16)

4.2 Maintenance Costs

In the judgement of engineers experienced in garage evaluations, maintenance is considered to be both necessary and cost effective. This applies to new structures and those which have been rehabilitated and upgraded in protection. Unfortunately no extensive data are available, but it is hoped that with the increasing activity now occurring, data will soon be reported. One garage inspected recently had been carefully maintained and the decks resealed with linseed oil every three years. After 56 years service, this structure appears to be in excellent condition.

As a result of a detailed life-cycle cost study of repair options for a municpal garage, it was suggested that between 1/4% and 1% of the value of a structure should be budgeted annually for maintenance of the structure and protective systems after it has been repaired. Recent experience suggests that this figure may need to be as high as 2%.

Assuming a 1984 Toronto cost of $300.00 per m^2 for the cost of an underground parking structure, the budgeted amount should therefore be between 75¢ and $6.00 per m^2 per annum.

4.3 Maintenance Manual

There is both a need and a demand for guidance on maintenance procedures.

With the kind permission of the National Parking Association of the United States, their parking garage maintenance manual (28) is reproduced as Appendix A. As this document was identified early in the project no further project resources were expended on this aspect of the project objectives.

The committee which produced this manual was made up of Engineers and others with extensive experience of the problems addressed by this research project. The manual is thus completely applicable to parking structures in Canada, and is in addition a very well produced, comprehensive, and relevant document.

5.0 EVALUATION AND DISCUSSION

5.1 Study Surveys

5.1.1 a Series Surveys

It is interesting to note that in the 1981 CMHC survey the garages surveyed were in effect chosen on a random basis, those surveyed being the ones for which the owners' permission was obtained. The surveys were carried out without any reference to the structural design or layout of the garages.

In this current survey sixteen garages were resurveyed, and reported as the "a" series and selected from the original CMHC survey having shown little, if any, need for maintenance, at the time of the original survey.

It can be seen now that there were good reasons why these should not have deteriorated. Firstly, none of them contained a suspended slab, all underground parking being on a slab-on-grade.

All were relatively small and, where there was a roof which was not internal and therefore completely protected, most were waterproofed by good roofing traditional practices with flashing and good drainage.

The only exceptions were either not used for parking or were now showing some signs of deterioration.

Clearly, such simple rigid structures of small size are not typical, but do exhibit characteristics which provide for durability and little deterioration. These characteristics are waterproofing, slabs on grade, low temperature, and good drainage.

Garages in this Ottawa sample were up to twenty-seven years old and most of them were more than ten years old. They had thus given long service with very minor repair costs.

5.1.2 b Series Surveys

The original intention in this phase of the study was to survey in detail a small number of structures which had proven to be durable, in the hope that some characteristics would be identified which could be related to their good durability. The results were not entirely as expected.

Structure b1 had a concrete topping over the structural slabs with saw-cuts on all grid lines. It is assumed that the topping was intended to protect the structural slabs and the saw-cuts were to provide a crack-control system for the topping. The survey showed that the overlay was highly permeable to chlorides, and extensively debonded from the structural slabs. Delamination has started in this eight year old structure, the chloride ion concentration at the level of the top steel was approximately ten times the threshold value, and a significant percentage of the structural slab areas showed corrosion to be active at the time of test.

While the design concept for protection was good therefore, the execution was defective, and deterioration may be expected to continue.

Structure b2, a cast-in-place post-tensioned structure was found to be in excellent condition eleven years after construction. Design criteria resulted in a well-drained, crack-free structure. All tests showed high quality construction practice. Together with the similar structures discussed in Section 5.1.4, it is felt that there is evidence of good durability for this design system. Uniform good cover, expansion joints in good condition, strong high-quality air-entrained concrete of moderate permeability to chloride ions, exposure to cold weather and some self-cleansing with good drainage were evident. With good maintenance including periodic resealing, it would appear that this system built to high construction standards can provide a good service life with minimal maintenance. Further confirmation by monitoring over an extended period and by obtaining data from a larger sample of this type of design would be desirable.

If, in addition, more positive protective systems are used to protect the anchorage zones and ensure the exclusion of corrosion from tendons, a high level of confidence in this design type should result.

Structure b3. To date, in the first five years since construction, little deterioration has occurred. Good uniform cover and air-entrained concrete, exposure to cold weather with some cleansing and good drainage appear to date to have worked well. Usage is also moderate and even within the structure there is a direct relationship between usage and chloride content. The high chloride contents in the most heavily used areas and the high chloride permeability of the concrete predicate the possibility of deterioration developing in the near future. Future monitoring for which this structure would be a good example, might help clarify whether or not the currently accepted value for chloride threshold is too low.

Structure b4. The unusually thick concrete topping and membrane (of multi-layer paper and mastic) were seen to have provided almost perfect protection to the structural slabs for twenty years. Durable garages can therefore be built. Also provided the membrane is adequately protected, as in this case, less sophisticated waterproofing systems function well.

5.1.3 c Series Surveys and Other Monitoring Data

The effectiveness of the repairs and protective systems are best judged by the rate of further deterioration since repairs. The following is a summary of this data. It should be remembered that all these structures were highly contaminated with chlorides at the time of repair. The sample was not biased but chosen to represent typical average projects to find out how well a number of repair and protection systems were functioning. It was noted that while deterioration continued after repair and waterproofing the corrosion activity had subsequently dropped significantly in all structures. This may result in further reduction in the rate of ongoing deterioration. Further monitoring would be required to investigate this.

Table 19
Summary of c Series Survey Data

Project	Age (Years)	Protective System	Damage (Percentage of slab delaminated) since repair	Time Since Repairs (Years)	Corrosion Activity
c1	13	W-3 (negligible permeability)	4.6	3	No active corrosion.
c2	16	W-4 over epoxy (nil permeability)	0.2	5	No active corrosion.
c3	26	Various	17.4	6	Active in 29.2% of area
c4	13	I-1 in cracks	N.A.	2	N.A.
c5	9	W-1 (low permeability)	1.0	2	28% active
c6	15	Sealer	80	2-3	48.7% active
c7	26	Asphalt	39.4	3	35.2% active
c8	9	W-2	1.8	5	1.7% active
c9	7	W-5 (nil permeability)	0.8	5	No active corrosion.
c10	21	W-3 on asphalt on epoxy	6.6	2	No active corrosion.
c11	10	S-1	57.1	2-3	Not tested
Private Project	9	W-3	8.3	3	2.3% active

c4 was an evaluation of a low-cost chemical injection system for repairing cracks from the egress side of a slab. It appears to work and therefore has some value provided it is understood that all it does is seal the cracks at the egress face. No changes made to the conditions in the ingress face of the structural slab or wall, and therefore deterioration may be continuing.

5.1.4 d Series Surveys - Above Ground Structures

In the steel frame structures, the frame was in good condition but the slab systems were in poor condition exhibiting no characteristics which would rate their durability higher than that of slabs in similar all concrete structures. The replacement of the slabs, however, is probably simpler where they are not part of the structural framing system. The post-tensioned concrete structure confirmed our findings for b2 that post-tensioned structures are generally in good condition. Evidence of replenishment of sealers supports the effectiveness of replenishment. The hybrid pre-cast cast-in-place and post-tensioned structure was exhibiting significant problems. The five reinforced concrete structures exhibited a good age -deterioration profile (relationship).

5.1.5 e Series Surveys

These demonstrated that the absence of structural slabs, no parking on roofs, small size, and little usage are factors all contributing to durability with long life and minor deterioration.

5.1.6 f Series Surveys

These confirm that while all underground suspended slab structures deteriorate, these older structures (prior to limit state design) deteriorate more slowly and where repairs have been carried out, extended the life in good condition of one of these structures.

5.2 Design Factors

All of the structures surveyed were located in major urban areas. It can thus be assumed that design criteria complied with building codes, current at the time of construction. Nothing noted in our surveys showed any significant deviation from these codes in construction except that the design and construction of expansion joints often failed to follow the best practice or even good practice.

5.2.1 Framing & Floor Systems

All below ground structures in the project sample were cast-in-place reinforced concrete frames. Most slabs were flat slabs or flat plates. The above ground structures included all cast-in-place reinforced concrete frames, steel frames with concrete slabs, cast-in-place post tensioned concrete, and in one case, composite prestressed pre-cast concrete beams with a post tensioned cast-in-place frame and floor slabs.

There was no evidence that the framing and floor system of itself was a factor in deterioration.

5.2.2 Sizing of Elements

Sizing of elements including spans, thicknesses, and widths all appear to be within the ranges normal to existing code designs. There was no evidence that the sizing of any elements was in itself a factor in deterioration. The only area where, subject to other factors, sizing could be a factor in deterioration would be in floor slab thickness. These ranged from six to ten inches with a few extremes as thin as four inches and as thick as fifteen inches. The average thickness was about eight inches.

5.2.3 Effects of Restraint

Usually parking structures appear to be extensively cracked. Subjectively this is how most appear to be. As shown in 3.2.1.2, however, when evaluated by objective criteria the incidence of cracking is perhaps not as great as judged subjectively.

In all the underground structures, the super imposed above ground structure provides restraints, to free movements below grade, but in no case was there evidence of significant structural cracking or other distress that could be attributed to such restraints.

In the aboveground structures of the project sample, the same applied. We have seen the strength problems in aboveground structures cause severe structural damage to columns or beams but these were exceptional cases.

5.2.4 Provision For Movements

It would appear that in most structures the Engineer has been successful in providing the number and location of movement joints. In general, however, the method of forming such joints, and the joint system itself leave much to be desired. Frequently movement is between two concrete surfaces separated, if at all, by polyethylene, masonite, or building paper. Often the concrete surfaces within the range of movement are rough and unsuitable to provide low friction coefficients. Frequently distress occurs at such locations as shown below in Fig. 14.

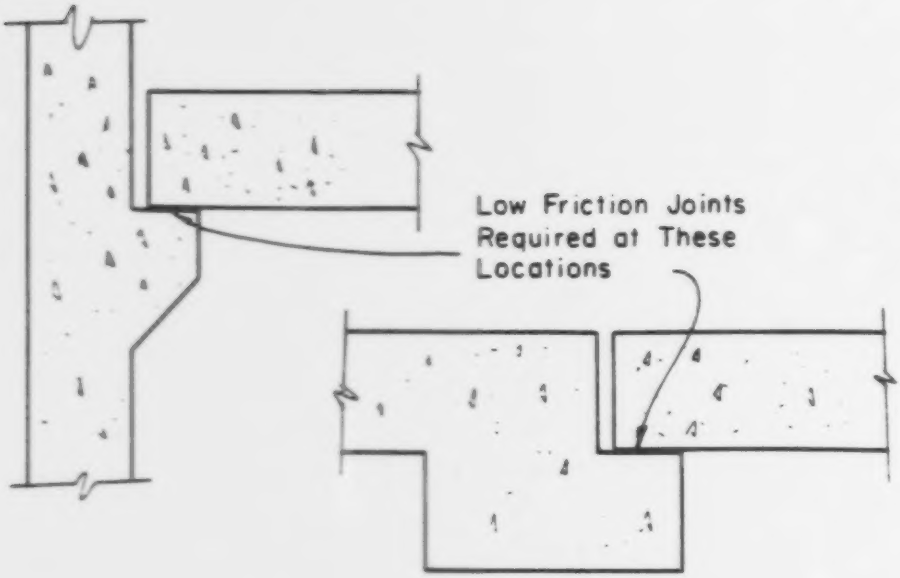

FIG. 14 MOVEMENT JOINTS

Such distress can have serious structural significance due to loss of bearing from spalling. Also, if cracking occurs and there is penetration by water, oxygen, and chlorides, the extent of deterioration will increase and more structural support may be lost.

It is frequently observed that after some years and the development of some distress, there is a reduction in the rate of further distress and deterioration. It appears that there may be an initial period in the life of some buildings during which all initial short-term, some long-term and seasonal effects are relieved by initial movement of the buildings, and thereafter stresses due to such causes are much reduced. Indeed, structures have been seen with poorly designed movement joints and yet no distress at all has occurred around such joints after many years of service. Clearly the location of movement joints is partially art and partially science.

Equally important to the provision of movement joints in the right locations is the system used to seal them. The majority of expansion joints in the structures surveyed were leaking or otherwise deficient. The use of unsuitable joint sealing systems, and deficient installation workmanship are seen to be the two main problems. It must be appreciated that a major underground parking facility can contain a large lineal footage of expansion joints. Three kilometres is not uncommon in major complexes. Since expansion joints of suitable quality can cost between $45.00 and $450.00 per metre, this is a major cost item and any reluctance on the part of a builder to use a good to high quality system is understandable. The cost of one kilometer of $450.00 per metre expansion joint is $450,000.00!

It seems inevitable therefore that there will almost always be a compromise between quality and cost in the choice of expansion joint materials. Essentially then, the choice of a low cost level system must predicate correct installation and regular inspection and maintenance if it is to be serviceable for a significant life.

5.2.5 Specification Criteria

5.2.5.1 Cover

It is clear that for underground garages the cover specified was normally 19 mm. This is in agreement with the code provided the environment is not judged to be corrosive, and until recently that was not considered by most designers. For exterior structures, specified cover would appear to be 38 to 50 mm.

In practice, as will be seen from the project sample data reports and the summary of other project data, average cover was generally in excess of that specified. For 36 projects summarized in 3.2.4.1 the mean was 42 mm. For the project samples, the cover where determined ranged from 0 to 105 mm.

In the structures surveyed in detail as part of this survey the relationship between the amount and variability of cover and the amount of distress can be summarized as follows:

Structure	Distress	Cover mm	Standard Deviation mm
b1	minor	0 - 55	5 - 10
b2	nil	39 - 49	7 - 8
b3	nil	28 - 44	6 - 13

It will therefore be seen that adequate and/or uniform cover was found in the structures seen to be in good condition.

Adequate and uniform cover are therefore seen to be factors in producing a durable structure.

Just as importantly, however, the variation in cover is generally seen to be high. Peterson has discussed at length the problems that arise in placing both reinforcement and concrete in parking decks. Multiple changes in levels and slopes create interface difficulties between slab and slab, and slab and beams or columns.

In addition, it should be appreciated that a large garage will have in excess of ten acres of parking slabs. The accurate placing of reinforcement and finishing of concrete over such large areas, frequently in competition with the effects of gravity is not easy.

The MTC determined that, at least for bridge decks, a diligent contractor can achieve a standard deviation of 10 mm in placing reinforcement. In practice this requires the use of an average cover 20 mm greater than the minimum desired. This implies a significant increase in slab thickness therefore if, for instance, a minimum of 50 mm cover is considered to be required. It would then be necessary to specify 70 mm ± 20 mm cover and this is in fact current MTC practice for bridge decks.

Until recently when specifying 19 mm cover, it has been assumed that this is the average, and the slab was designed on this assumption. The accepted tolerance for placing was ± 6 mm. Clearly from the data now available from surveys, little checking has ever been done.

The implication therefore from a design point of view would be to go from an average of 19 mm cover to a design cover of 70 mm, an increase in slab thickness of 51 mm just to provide a 50 mm minimum cover. This obviously has significant cost implications.

5.2.5.2 Concrete Quality

It seems clear that if concrete alone is to provide significant protection to reinforcement in a corrosive environment then it is necessary to use either conventional concrete with a water cement ratio not greater than 0.40 or to use exotic or semi-exotic concrete incorporating polymers (such as latex) or superplasticisers, or pozzolans, such as fly-ash, slag, or silica fume, or combinations of these.

We have not found in any of the projects surveyed, a specification of a very high quality concrete. For underground garages it has been common to specify primarily by strength, usually 20 or 25 MPa. As stated earlier, while structurally adequate, such concretes will have high chloride permeability. Of course going from a cement content of 230 kg/m^3 of concrete to 375 kg/m^3 would add about $15.00 to the cost of each cubic metre of concrete.

For some exterior structures CSA Class A exposure criteria have been specified, and if followed a good quality concrete with a maximum water-cement ratio of 0.45 should result. It is clear however that even this quality of concrete, even with a minimum cover of 50 mm, will not in itself guarantee a long life slab though it would significantly extend such a life. The use of such high cement contents introduces other factors such as the probability of increased cracking. The strength of such concrete would almost always be very much higher than required for structural purposes.

5.2.5.3 Protection

Protection in the context of a parking structure is taken to mean protection from corrosion by the:

a) use of extra cover,
b) application of a surface treatment, or
c) use of corrosion resistant reinforcement.

The use of cover has been discussed above. The use of corrosion resistant reinforcement postdates the study sample.

Our data does not show whether or not protection in the form of sealers or waterproofing was specified for any of the sample structures.

In the case of structure b1 it seems clear that the concrete topping was intended to protect the structural slab. Similarly, in structure b4 the heavy-duty waterproofing system (9 mm) with an unusually thick concrete topping (98 mm) fulfilled the same function.

It is suspected that in structures b2 and b3, sealing was specified at the time of construction.

The surveys of structures d2, d4 and d5 show that sealers (with periodic replenishment) can provide good protection. Data on structures d6, d7, and d11 confirm that sealers do have to be renewed to provide protection.

5.3 Construction Factors and Field Practices

5.3.1 Quality of Concrete

Strength is not seen to be a problem. Typical values for sixty projects were shown to be the equivalent to specified strength of between 32 and 67 MPa with a mean of 47 MPa. Project sample core data showed equivalent specified strengths of 38 MPa for a reinforced concrete private structure, 58 MPa for a Government reinforced concrete building, and 59 MPa for a post-tensioned structure. In view of the high mean, strength is clearly not itself a measure of durability.

5.3.2 Deflection and Cracking

It has long been accepted that formwork should not be removed until the strength of the concrete reaches a level (usually about 75% f'_c) at which no significant deflections will occur due to creep and shrinkage.

It is thought that one factor causing poor drainage and ponding in parking decks is deflection that might be related to premature form removal. It is difficult to identify this factor after the fact.

Only in one project was there evidence of structural cracking resulting from deflection. Assuming design to code requirements, it is thought likely that this cracking resulted from premature form removal. In the interior environment in which it occurred however, it has not resulted in deterioration or any structural problem.

Visually, garage slabs generally appear to be extensively cracked. By an objective rating system, however, the extent of cracking is not usually excessive for the type of structure. The project sample was typical in this regard. The influence of cracking on corrosion is not fully understood. Some consider it to have little effect while others, based on observations, feel that in flexible structures it may be of significance due to the effect of cracks working.

5.3.3 Cover

It is commonly recognized that cover to reinforcement in parking structures is frequently variable. Partially exposed bars are common. The data shows that only in a small minority of the cases quoted did cover meet the recently decided MTC criteria of excellence (standard deviation not greater than 10 mm).

It is therefore clear that standards of placement need to be improved. Also for any specified minimum cover, slab thickness will have to be increased to guarantee minimum cover since the minimum cover will equal the specified cover minus two standard deviations.

Perhaps structural engineers will have to decide if an average cover value is satisfactory for structural purposes.

It was noted that covermeter tests and physical measurements of cover differ slightly.

5.3.4 Chloride Contamination

5.3.4.1 Amount of Chloride

The test procedure used to determine soluble chlorides has been shown to be reliable and reproducible, with low in-test and between laboratory variation.

Typical values found in many surveys show an average chloride content at the level of the top steel of about six times the threshold value. Quantities as high as thirty times the threshold value have been found. It must be assumed that any unprotected parking deck will reach the threshold value of chlorides early in its life.

The allowance by CSA Standard CAN3-A23.1-M77, of the use of calcium chloride, is shown to result in an chloride ion content many times the threshold value for corrosion.

Clearly this provision should be changed to ban calcium chloride. It is also noted that the average chloride content at the level of the top reinforcement is almost twice that reported for bridge decks.

5.3.4.2 Chloride Permeability

The rapid chloride permeability test developed by Whiting(53) appears to offer the best method to date for testing for chloride permeability. The test appears to work well for exposed concrete specimens and for dielectric coatings. There is some doubt about results obtained for partially dielectric materials, and possibly where concrete is already chloride contaminated, although our data for chloride contaminated specimen appears to be reasonable. In the latex modified specimens for instance, the results were the same after ninety days of ponding with sodium chloride as well as for specimens without ponding. Most of the waterproofing systems tested showed nil permeability. It is interesting to note that in the case of Structure c6, a coal tar epoxy waterproofing (without membrane) was found to have very low permeability even though epoxy is dielectric. It must be assumed therefore that the permeability had developed in service due to wear, cracks, or weathering. In the case of waterproofing system W-3, the negligible permeability found was discounted by the manufacturer who maintains that the test is inappropriate for his material which while shown to be impermeable to chlorides in other standard tests, is not completely dielectric and is affected by the forcing DC current used in this test.

Results for the three residential underground parking structures, Table 16, Section 3, were all very high to the point that whatever the cover, very little protection would have been provided by the concrete.

Results for the post-tensioned structures, both normal and lightweight concrete, were good being in the low to moderate range for both concretes. The values are not however low enough to warrant the ommission of protection in the form of either an effective sealer or waterproofing.

Similarly, the concrete in an institutional structure was found to have low permeability.

Asphaltic overlays were found to vary from nil permeability to very high permeability and therefore cannot be relied upon to provide waterproofing although the effect of some protection has been seen in structures.

With regard to concrete overlays, the normal concrete topping in Structure b1 had such high permeability it provided very little protection while the proprietary reinforced topping on Structure c5 provided very good low permeability protection as did the waterproofed mortar used in Structure c6.

With regard to sealers, the data is more difficult to interpret.

In one post-tensioned structure where a sealer was recently applied under controlled conditions, this sealer was shown to reduce the chloride permeability by more than 50%.

However, in the other structures tested in the project sample, the residential properties were shown to have a very high permeability in the sealed concrete in two cases and in the other one the results were both variable and difficult to interpret.

The criteria suggested by Whiting for classifying chloride permeability are shown in 2.10.9.3. Concretes with coulomb counts in excess of 4,000 are classified as highly permeable to chlorides. Coulomb counts of between 2,000 and 4,000 would classify concrete as moderately permeable to chlorides, and would generally indicate water-cement ratios of between 0.40 and

0.50. Even in this range, however, concrete would not be adequate without protection to resist chloride penetration over the service life of a structure.

As will be seen in structure b1, the concrete topping provided, presumably to protect the concrete slab, was in itself so highly permeable to chlorides the test apparatus overheated and all three tests had to be abandoned. In c6, a free standing garage built for a hospital, chloride permeability was shown to be moderate but the concrete slabs were up to 67 % spalled when surveyed about four years ago. The data given for two other structures, both typical apartment buildings, show very high permeability to chlorides as would be expected.

Project sample structures tested showed variable chloride contents. Structure b1 of reinforced concrete but with a topping that cracked and was also shown to be very permeable to chlorides had between six and fifteen times the threshold value.

Structure b2 with post-tensioned slabs and concrete of good chloride permeability had below threshold values, two out of the three values being very low and the only high one being found in the only area where rust was seen in the structure.

In the above grade parking structure b3, while the average chloride content was above the threshold value, the upper parking levels had values below the threshold while the lower parking levels were very high in chloride content. Since the lower the level, the greater the usage, the correlation with usage is interesting.

5.3.5 Effectiveness of Joints and Drainage

With very few exceptions we have not seen effective joints. In the majority of structures, including project sample structures, a significant percentage of total joint length was leaking or otherwise defective.

Drainage in the typical underground garage is generally ineffective due to poor slopes to drains.

5.3.6 Quality of Protection

Structure b1 was protected by a concrete topping which as discussed above, failed because it cracked extensively and was highly permeable. Structure b4 on the other hand was protected by a 9 mm thick waterproofing system plus a 98 mm thick concrete topping. Protection to the structural slabs after twenty years appeared to be absolute.

Structures b2 and b3 have exposed concrete slabs but it is thought that these were both initially protected by a sealer. None was visible at the time of survey nor was there any evidence of re-application.

Chloride permeability tests on various waterproofing systems showed generally nil permeability even after years of service thus demonstrating a very high degree of protection.

5.3.7 Delamination

This is usually the most costly repair item. If unrepaired, delaminations increase at very variable rates. No consistency has been found in this increase which can range from a few percent to hundreds of percent per year.

On average, garages were found to contain about 13% delamination at the time of repair. Averages for garages range as high as 50% with individual parking levels as high as 70%.

5.3.8 Carbonation

Another major factor in the deterioration of concrete, but one which has been largely overlooked in North America to date, is the effect of carbonation on the concrete. Since alkaline materials react with highly acidic solutions of carbon dioxide, they are unstable in atmospheric conditions. The alkalinity of concrete is therefore reduced as a result of reaction between acidic atmospheric gases and the concrete matrix. Major factors in the rate at which such carbonation occurs are the permeability of the concrete itself and the extent to which it is cracked. The extent of carbonation can be readily determined by a simple phenolphthalein test, and can be confirmed by chemical analysis to determine the pH of the concrete.

Since permeability and cracking are two of the major factors present in deteriorated parking structures, it is clear that some of the deterioration must relate to carbonation, and indeed some tests made recently on deteriorated parking decks have confirmed extensive carbonation. Obviously anything that prevents or delays the ingress of carbon dioxide into concrete to the vicinity of the reinforcing steel will slow down or prevent this cause of disruption. Such remedial measures are obviously the use of impermeable concrete, greater concrete cover, reduction of cracking, or surface protection by waterproofing or other means.

5.4 Environmental Factors

There was no evidence from our survey that environmental factors other than those created by weather and the application of de-cing salts had any effect on parking structures.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 "Why Are The Good Ones Good?"

The following factors have been shown by the data in this study to contribute to durability and where appropriate should be incorporated into the design and construction of new structures.

- Design -
  - Crack free design by post-tensioning.
  - Good quality expansion joints.
  - Adequate provision for movement.
  - Good cover (about 40 mm in exposed structures).
  - Good drainage.
  - Air entrainment (in exposed structures).
  - High quality waterproofing system protected from wear.
  - Sealers replenished periodically.
- Construction -
  - Uniform cover.
  - Good quality concrete.
    - Adequate air void system.
    - Adequate chloride impermeability.
    - Adequate strength.
    - Well finished.
  - Good slope for drainage.
  - No construction induced deflection or cracking.

- Usage -
  - Low usage rate.
  - Maintenance.
  - Re-sealing of exposed decks.

The project data shows that it is possible to build a durable garage.

6.2 "How Do We Best Deal With The Bad Ones Now?"

The picture is not clear, the sample size in most cases being very small. Within these limitations however, some tentative conclusions can be drawn.

Deterioration rates after repair and sealing are very high.

Deterioration rates after repair and waterproofing range from almost nil (where good protection was originally provided by a protective coating without a membrane and deterioration had been limited to the vicinity of cracks) to almost 3 % new delamination per year. The average was about 0.9 % per annum. It is reasonable to expect about 1 % delamination growth per year after repair and the application of a good quality waterproofing. It should be remembered however that the data available only relates to a maximum of five years experience after the repair and the reasons for the higher rates of post-repair deterioration have not yet been identified. It seems clear that the only completely satisfactory answer is to either build them durably to start with or totally replace contaminated concrete. The data shows however that repair and waterproofing did on average reduce the ongoing rate of deterioration to little more than a quarter of what it was prior to repair.

The use of a waterproofing system after repair is thus shown to be a cost-effective approach to rehabilitation.

6.3 Recommendations For Future Research

6.3.1 Condition Surveys & Testing

6.3.1.1. Rapid test method for the determination of the amount of chloride ions available to cause corrosion.

It is not known at this moment to what extent chlorides added to the concrete in the form of admixtures or those mixed in as part of the original ingredients can affect the threshold value in the concrete. A test procedure is therefore necessary which can distinguish between the total amount of chlorides in a concrete and that fraction of this total which is available for corrosion.

6.3.1.2 Measurement of delamination.

A cheap, simple, semi-automatic method for the measurement of delamination quantities in confined areas is required. The amount of delamination damage is a major percentage of total rehabilitation costs and an economic method is therefore required so that complete delamination surveys can be carried out at acceptable cost.

6.3.1.3 Chloride permeability.

Existing chloride permeability tests require further development to define the characteristics of old concrete contaminated with chlorides and old concrete which has been sealed for a period prior to testing.

6.3.1.4 Bond testing.

Since bond between the old and new material is the most important characteristic of a repair, present bond-testing systems need developing and correlated data between laboratory and field produced, so that a universal standard for this method of testing can be adopted.

6.3.1.5 Data Processing

A method for simplifying the data processing, plotting, and analysis of half-cell tests, cover determinations, delaminations, and crack data. The use of computer plotted drawings should be investigated.

6.3.2 Repair Methods

6.3.2.1 Removal of damaged concrete.

Equipment is required for the removal of damaged concrete without leaving residual damage in the substrate. It is clear that jackhammers and sandblasting, no matter how carefully applied, together leave a bruised layer in the substrate. This results in less than ideal bond between the repair concrete and the parent concrete. Methods such as high-pressure water blasting need development so that concrete can be removed economically without damaging the good concrete that remains.

6.3.2.2 Movement joints.

Further development is required in the field of low-cost effective expansion joints and sliding bearings.

6.3.2.3 Cost analysis of repair systems.

A further, and substantial, cost analysis should be made of the life-cycle costs of various repair systems based on actual performance. This data should be analysed from a data bank which could result from a project to collect and evaluate data. This data bank would be obtained from a number of consultants who would synthesize their knowledge and submit it to the central authority.

6.3.2.4 Adhesives, sealers, joint sealing compounds and waterproofing systems.

A survey should be made of all products available plus any data relating to their evaluation that is available in the public domain.

6.3.2.5 Assessment of repair systems.

An assessment should be made of various materials and repair systems with regard to their installation including limitations of access available, suitable plant, etc.

6.3.2.6 Monitoring

Significantly more monitoring should be carried out to produce field performance of repair and protection systems.

6.3.3 Repair Materials and Protective Systems

6.3.3.1 National standards for protective systems.

Standards are required for the materials and their performance in the laboratory and the field. These materials would include sealers, waterproofing systems, and integral corrosion inhibitors.

6.3.3.2 Cathodic protection systems.

Economic cathodic protection systems are required which can be applied to the large flat or sloping areas of parking structures.

6.3.4 Design

6.3.4.1 Cracking in structures

A model should be developed for the prediction of major cracking in structures. This should be based on a survey and experience, and studies of relief of restraint in various structural systems.

6.3.4.2 Cost Analysis of design systems.

A cost analysis should be made of the relative merits of increased cover, epoxy coated rebar, crack control systems, sealing and waterproofing systems, more effective slopes, and more drainage. Such studies should determine life-cycle costs.

7.0 BIBLIOGRAPHY

1. Recommendations For Non-Destructive Methods Of Test For Concrete, Part 1 Electromagnetic Cover Measuring Devices. BS 4408: Part 1: 1969.

2. Designing Durable Maintenance-free Prestressed Concrete Parking Structures, H. C. Walker, Concrete Construction, July 1977.

3. Durability of Concrete Bridge Decks, National Cooperative Highway Research Programme Synthesis Of Highway Practice 57, Transportation Research Board, Washington, May 1979.

4. Parking Structure Reconstruction. A Case History. The Cause Of Failure, Repair Methods Used And The State Of The Art, P. R. Ramsay, ACI Seminar, Ottawa, November 1979.

5. ACI Survey Of Concrete Structure Failures, J. Fraczik, Concrete International, December 1979.

6. Something For Nothing - Almost, P. Klieger, Concrete International, January 1980.

7. Designing Parking Structures To Minimize Maintenance, by P. Shah, Concrete International, March 1980.

8. Principles Of Watertight Concrete Construction For Parking Structures, by D. Monroe, Concrete International, March 1980.

9. Parking Structures - Construction Problems And Solutions, R. T. Tucker, Concrete International, March 1980.

10. Durability Of Parking Structure Floors, H. C. Walker, Concrete International, March 1980.

11. Survey Of Parking Structure Deterioration And Distress, C. A. Peterson, Concrete International, March 1980.

12. Rehabilitation Of Parking Decks With Super-plasticized Concrete Overlay, S. G. Pinjarklar, A. E. N. Osborn, M. J. Koob, D. W. Pfeifer, Concrete International, March 1980.

13. The Deterioration Of Parking Structures, J. A. Bickley, Canadian Society For Civil Engineering, 1980 Annual Conference, Winnipeg, Manitoba, May 1980.

14. Design Of A Multi-Use Municipal Parking Garage, G. R. Lloyd, Concrete International, May 1980.

15. Detecting Delaminations In Concrete Bridge Decks, D. G. Manning and F. B. Holt, Concrete International, November 1980.

16. Interim Guidelines: Investigation, Repairs, Design and Construction of Parking Structures, Ontario Chapter ACI, August 1981.

17. The Investigation And Repair Of Parking Structures, J. A. Bickley, American Concrete Institute Fall Convention, Quebec City, September 1981.

18. Design Objectives In Planning Parking Structures, T. R. Seeberg, American Concrete Institute Fall Convention, Quebec City, September 1981.

19. Concrete Structural Systems, N. E. George, American Concrete Institute Fall Convention, Quebec City, September 1981.

20. Design And Construction Considerations For Concrete Parking Structures, D. Munroe, American Concrete Institute Fall Convention, Quebec City, September 1981.

21. How To Live With A Concrete Parking Structure, R. W. Lewis, American Concrete Institute Fall Convention, Quebec City, September 1981.

22. Nature, Extent, And Impact Of Residential Parking Structure Deterioration, J. A. Bickley, Central Mortgage and Housing Corporation File No. 5640-21, November 1981.

23. Analysis And Modeling Of Corrosion Of Steel In Prestressed Concrete, S. T. Wu and J. R. Clifton, USBSIR 81-2390, November 1981.

24. Concrete Sealers For Protection Of Bridge Structures, NCHRP Report 244, December 1981.

25. New Precast Parking Garage Has Unusual Structural Features, G. M. Chamberlain, Concrete International, December 1981.

26. Concrete Sealers For Protection Of Bridge Structures, National Cooperative Highway Research Program Report 244, Transportation Research Board, National Research Council.

27. Durability Of Tendons In Prestressed Concrete, Concrete Society Technical Report No. 21, 1982.

28. Parking Garage Maintenance Manual, Parking Consultants Council, National Parking Association (U.S.) 1982.

29. An Analysis Of Performance Failures Of Parking Structures, J. A. Bickley, Conference On Building Science: Design And Rehabilitation Of Building Envelopes, The Canadian Society For Civil Engineering - Ontario Region, London, Ontario, March 1982.

30. Detecting Delamination In Concrete Bridge Decks, D. G. Manning and F. B. Holt, M.T.C. Report MC-80-82, July 1982.

31. Evaluation And Repair Of Deteriorated Garage Floors, G.G. Litvan, CBD 225, Ottawa, July 1982.

32. Deterioration Of Indoor Parking Structures, G.G. Litvan, CBD 224, Ottawa, July 1982.

33. The Durability Of Steel In Concrete, Parts 1 to 3, BRS Digests 263, 264, and 265, July, August and September 1982.

34. Solving Rebar Corrosion Problems In Concrete, Proceedings NACE Seminar, Chicago, September 1982.

35. Tentative Recommendations For The Corrosion Protection Of Unbonded Tendons, FIP Committee Report, PCI Journal, Jan/Feb. 1983.

36. Cracking, Cover, And Corrosion Of Reinforcement, A. W. Beeby, Concrete International, February 1983.

37. Study Of Residential Intensification And Rental Housing Conservation Part 4, Klein & Sears et al, March 1983, Prepared for the Ontario Ministry of Municipal Affairs and Housing and the Association of Municipalities of Ontario.

38. Performance Des Membranes, D'Etancheite Utilisees Au Quebec Et Evaluation En Laboratoire De La Qualite Des Membranes D-Impermeabilisation, D. Vezina, MOT Quebec, 1983.

39. Long Term Rehabilitation Of Salt Contaminated Bridge Decks, NCHRP Report 257, April 1983.

40. Parking Structures: Problems And Repair, M. Poldma, Thesis, Toronto, April 1983.

41. Short Term Chloride Penetration Into Relatively Impermeable Concretes, W. F. Perenchio, S. L. Marusin, Concrete International, April 1983.

42. The Management Rehabilitation And Preservation Of Our Parking Structure Inventory, J. A. Bickley, The Canadian Society For Civil Engineering, 1983 CSCE Canadian Structural Concrete Conference, Ottawa, Ontario, June 1983.

43. Corrosion Of Reinforcement In Concrete Construction, Proceedings, Chemical Society, London, England, June 1983.

44. Investigation And Repair Of Post-tensioned Concrete Slabs - A Case History, S. Hom and G. Kost, Concrete International, July 1983.

45. Concrete Buildings Are Cracking Up, The Economist, October 15, 1983.

46. Design Considerations For Corrosion Control Of Reinforcing Steel In Concrete Structures. Proposed NACE Standard Draft 2, October, 1983.

47. How Accurately Can Reinforcing Steel Be Placed? Field Tolerance Measurements Compared To Codes, P. R. Morgan, T. E. Ng, N. H. M. Smith, G. D. Base, 1983.

48. Parking Structures: Overview Of Design And Other Requirements, N. D. George, Construction Canada, November 1983.

49. Glass Fibre Reinforced Cements In The Repair Of Concrete Parking Structures, I. Razl, Construction Canada, November 1983.

50. Towards A Durable Parking Deck, J. E. Jones, Construction Canada, November 1983.

51. Deterioration of Concrete Structures In The Environment Of The Middle East, Rasheeduzzafar, F.H. Datzhil, and S. Al-Gahtani, ACI Journal, January/February, 1984.

52. Design Recommendations For Multi-Storey And Underground Car Parks, R. Sharp, Journal Of Institution Of Highways And Transportation, February, 1984.

53. In Situ Measurement Of The Permeability Of Concrete Chloride Ions, D. Whiting, Conference On In Situ/NDT Testing Of Concrete, Ottawa, October, 1984.

APPENDIX A

PARKING
GARAGE MAINTENANCE MANUAL

Prepared by
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FOREWORD

The National Parking Association, founded in 1951, is the trade association of America's parking industry with membership throughout the free world. The Parking Consultants Council is a special professional group within NPA which is concerned with economic analysis, functional and structural design, financial counseling, analysis and maintenance of off-street parking.

The recommended parking garage maintenance provisions that follow are intended to be general guidelines for the maintenance of parking garages and are not intended to cover all aspects of parking garage maintenance. Owners and operators of parking garages should carefully evaluate whether these recommended parking garage maintenance provisions are appropriate for the parking garages for which they may be concerned or responsible. Consultation with a qualified engineering consultant is recommended for portions of garage maintenance program.

Since any maintenance program must conform to the requirements and conditions of the local jurisdiction and specific facility concerned, neither the National Parking Association nor the Parking Consultants Council assumes any responsibility for damages arising from the use of application of these recommended parking garage maintenance provisions.

The manual is the result of work done by the firm of Carl Walker and Associates, Inc., under the direction of Anthony P. Chrest, Senior Vice-President, and efforts of a committee of NPA's Parking Consultants Council, comprised of Howard R. May, Chairman, with Bernard Dutch, Robert Lathan and Charles Sharitz, Federal APD, a division of Federal Signal Corporation, contributed the appendix on the maintenance of parking control equipment. Appreciation is also due to the many others who reviewed drafts of the text and offered constructive comments and encouragement.

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PARKING GARAGE MAINTENANCE MANUAL

INTRODUCTION

This manual is intended to provide the owner and/or operator with guidelines for maintaining a parking garage at a satisfactory level of service. Practices and procedures considered essential to the prevention of equipment failures and premature deterioration of the concrete or steel structure are discussed along with other aspects of maintenance that involve cleaning and aesthetics.

This manual is intended to apply to parking garages of all types. This includes free standing parking garages, underground parking garages and parking garages that are constructed integrally with other facilities such as apartments and office buildings. Many different terms are used to describe structured parking facilities. The reasons for the different terms include building code definitions, local custom and others. Some of the common terms include parking deck, parking ramp, parking structure, garage, parking garage, multi-level parking deck, parking facility, and open parking structure. This manual will use the term "parking garage" to apply to all situations.

While the maintenance requirements of many elements of a parking garage are similar to their counterparts in other type buildings, the frequency of required attention may be different due to more severe exposure conditions. Because very little has been written about the specific maintenance required for the structural system of parking garages, this subject is discussed in greater detail than other aspects of maintenance.

The terms "maintenance" and "preventive maintenance" are used with the following connotations in this manual. In general, the term "maintenance" is used to refer to all tasks required to maintain a facility at satisfactory levels of service including cleaning, lubrication of mechanical parts, concrete surface coatings, minor repairs and other maintenance tasks. The term "preventive maintenance" is generally used to specifically denote those tasks that are designed to prevent the need for major repairs at some future time.

The various geographic areas result in widely varying exposure conditions for parking garages. Thus, this manual can only point out the problem areas and present broad recommendations. These recommendations must be tempered for each structure and its specific climate. It is recommended that the owner/operator engage an experienced qualified engineering consultant to assist in developing a maintenance program specifically for each parking garage.

The service environment of a parking garage is more severe than most other buildings. The service environment is more nearly like that of highway bridges. In some areas of the country, extensive use of salt in winter often causes contamination of the concrete with chlorides that can result in corrosion of reinforcing steel and damage to the concrete. In all geographic areas, temperature changes and moisture provide a more severe service environment for parking garages than for other buildings.

The amount of maintenance work required for an individual parking garage will depend upon the design details and materials used in the structure as well as the exposure conditions. The details and materials for some parking garages have been selected specifically with minimum maintenance and long-term performance in mind, while in others, less importance may have been placed on these items.

In the following portions of this manual, various aspects of parking garage maintenance are discussed. In the next section (Recommended Maintenance Program) a checklist recommends a desirable frequency and minimum frequency for many maintenance items. The text indicates the amount of effort suggested for each item. Many of the items on the checklist are simply inspections of the conditions. If abnormalities are found during the inspection, appropriate corrective action should be implemented. Some of the items are related to the appearance presented to the public, some are related to safety, while others pertain to preventive maintenance that will help avoid costly repairs in the future. Preventive maintenance is usually more cost effective than breakdown maintenance and certainly less disruptive to operations.

Many parking garages are leased by the owner to a parking operator for day to day operation. Although "maintenance" is often designated as the responsibility of the operator, the level of maintenance desired or the need for regular preventive maintenance programs has often been neglected in such agreements. It is important that lease agreements clearly define the maintenance responsibilities in detail. The other party should be obligated to inform the party responsible for maintenance of observed needs for either maintenance or repair.

Similarly, when one party has the responsibility for the maintenance, the second party should have the right to do maintenance work or make repairs with appropriate reimbursement, should the first party fail to do so with reasonable notice.

What are some of the consequences of deferred maintenance? Failures associated with some operational features such as lighting, parking equipment or security monitoring devices are relatively easy to correct and may cause inconvenience or loss of revenue. Deferred structural maintenance can lead to serious deficiencies which, in an extreme case, may result in partial collapse of the structure. Premature deterioration of concrete floors is costly - both in the cost of repairs and the loss of revenue while repairs are underway. In multi-purpose structures where parking floors are integrated with other uses, the deterioration of parking floors could affect the integrity of the whole structure and its other uses.

In addition to the operational and structural consequences of deferred maintenance, there may be serious legal consequences as well. Where there is a code or regulatory violation, the owner or operator responsible may be held liable for any damages or injury that result. That is, depending on state law, a code violation resulting in damages or injury may have the effect of imposing a strict concept of negligence. In extreme cases involving violations of fire or building codes, personal criminal liability may be imposed.

In other cases not involving a code violation, a plaintiff's case is strengthened if he can demonstrate that a failure of maintenance contributed to the damages or injury. Typical of such maintenance neglect would be trash on stairways, inoperable lights contributing to a fall, or inoperable security devices such as doors or alarms which contribute to an assault. Prudent preventive maintenance cannot insure that you will not be sued for damages or injuries, but it can distinctly reduce the likelihood that such suits will be successful.

A comprehensive maintenance program requires that a budget be established to support that maintenance program. This budget should be on an annual basis and should begin with the first year of operation. Some major items, such as the reapplication of protective concrete sealers, occur at intervals of several years and must be planned for in the maintenance budget.

In summary, a comprehensive maintenance program is required for each parking garage. The specific program for a given structure will depend upon many factors including design detail, quality of materials, construction quality and exposure conditions. To function at required performance levels, all elements of a parking garage need periodic maintenance, as does any other building or piece of equipment.

RECOMMENDED MAINTENANCE PROGRAM AND CHECKLIST

The recommended maintenance program that is outlined in the following checklist, text and in the appendix is intended to cover most typical aspects of maintenance including those related to cleaning, safety, equipment, and structure. For convenience, the maintenance program is divided into 15 descriptive sections and listed alphabetically. These are:

1. Cleaning
2. Doors and Hardware
3. Electrical Systems
4. Elevators
5. HVAC (Heating, Ventilating, Air Conditioning)
6. Landscaping
7. Painting
8. Parking Control Equipment
9. Plumbing Systems
10. Roofing and Waterproofing
11. Safety Checks
12. Security System
13. Signs (Graphics)
14. Snow and Ice Control
15. Structural System

It is recommended that for each parking garage, a specific maintenance program be developed. This specific maintenance program should include:

- A schedule of cleaning, inspections, lubrication, and other maintenance activities.
- Records of preventive maintenance performed on any element, and logs of both service calls and the types of repairs made.
- Fixing of responsibility for implementing and carrying out the program.
- A control system by management to verify that the maintenance program is being carried out and is effective.

The checklist that follows is intended as a guide to many of the items in a parking garage that should be checked or may be expected to require attention at regular intervals. A suggested desirable and minimum frequency of observation or attention are indicated by a "D" and "M" respectively.

Following the checklist is text which amplifies and/or explains the typical tasks that are recommended. Each heading on the checklist notes the beginning page number in the text pertaining to that section.

Recommended Frequency
D = Desirable
M = Minimum

	Daily	Weekly	Semi-Monthly	Monthly	Quarterly	Semi-Annually	Annually	Other
1. **Cleaning** (page 9)								
• Sweeping - localized	D	M						
• Sweeping - all areas (incl. curbs)		D		M				
• Trash cans	D	M						
• Toilets - floors, fixtures	D	M						
- walls				D	M			
• Cashier Booths - floors, windows	D	M						
• Elevator - floors	D	M						
- walls, windows				D		M		
• Stairs - floors		D		M				
- windows					D		M	
• Lobby, Office - floors	D	M						
- windows		D		M				
• Wash parking floors				D		M		
• Parking control equipment		D	M					
2. **Doors & Hardware** (page 11)								
• Check for proper operation	D	M						
- Doors close and latch properly	D	M						
- Mechanized doors	D	M						
- Panic hardware at security doors	D	M						
• Lubricate mechanized doors				D		M		
3. **Electrical System** (page 12)								
• Check light fixtures		D		M				
• Relamp fixtures								Note 1
• Special units - inspect								Note 1
• Distribution panels						D	M	
4. **Elevators** (page 13)								
• Check for normal operation	D	M						
• Check indicators and other lights	D	M						
• Preventive maintenance service (Also see **Cleaning**)								Note 2
5. **HVAC** (page 14)								
• Check for proper operation				D	M			
• Check ventilation in enclosed or underground garages	D/M							
• Preventive maintenance service								Note 1
6. **Landscaping** (page 14)								
• Remove trash	D		M					
• Gardening - mow, trim, weed		D		M				
7. **Painting** (page 15)								
• Check for rust spots								
- Doors & door frames						D	M	
- Handrails and Guardrails						D	M	
- Pipe guards, exposed pipes & conduit						D	M	
- Other metal						D	M	
• Check for appearance								
- Striping						D	M	
- Signs				D	M		D	
- Walls						D	M	
- Curbs				D		M		
• Touch-up paint						D	M	
• Repaint								Note 1
8. **Parking Control Equipment** (page 16)								
• Check for proper operation	D	M						
• Preventive maintenance (See **Cleaning** and **Appendix**)								Note 3

Recommended Frequency D = Desirable M = Minimum	Daily	Weekly	Semi-Monthly	Monthly	Quarterly	Semi-Annually	Annually	Other
9. Plumbing Systems (page 17)								
• Check for proper operation								
- Sanitary facilities	D	M						
- Irrigation			D	M				
- Floor drains	D		M					
- Sump pump		D		M				
- Fire protection system				D	M			
• Drain water systems for winter							M	
10. Roofing and Waterproofing (page 19)								
• Check for leaks								
- Roofing				D		M		
- Joint sealant in floors				D		M		
- Expansion joints				D		M		
- Windows, doors, walls				D		M		
- Floor membrane areas				D		M		
• Check for deterioration						D	M	
11. Safety Checks (page 20)								
• Carbon monoxide monitor	D	M						
• Handrails & guardrails				D	M			
• Exit lights		D		M				
• Emergency lights		D		M				
• Tripping hazards		D		M				
12. Security System (page 21)								
• Check for proper operation								
- Closed circuit TV	D	M						
- Audio surveillance	D	M						
- Panic buttons	D	M						
- Stair door alarms	D	M						
13. Signs (Graphics) (page 22)								
• Check signs for:								
- in place	D	M						
- clean				D	M			
- visible	D	M						
- legible				D			M	
- illuminated	D	M						
14. Snow & Ice Control (page 22)								
• Check for icy spots (in season)	D/M							
• Remove snow and ice	As required							
15. Structural System (page 24)								
• Check for:								
- Floor surface deterioration						D	M	
- Water leakage						D	M	
- Cracking of concrete						D	M	
- Rust of structural steel						D	M	
• Repair	See text							
• Replace protective concrete floor coating	See text							

Notes for Maintenance Checklist

1. A frequency should be selected that is appropriate for that element in the specific parking garage. Spot repairs or replacement should be done as needed.
2. This equipment should be under a service contract for regular preventive maintenance service and emergency service. The equipment manufacturer's recommendations for inspection and preventive maintenance should be followed.
3. This equipment should either be under a service contract for regular preventive maintenance service and emergency service or in-house staff should be specially trained to provide the required service. The equipment manufacturer's recommendations for inspection and preventive maintenance should be followed.

1. CLEANING

Included in this section are discussions of:

- Sweeping floors
- Washing floors
- Trash pick-up
- Windows
- Other cleaning -
  - Walls
  - Elevators
  - Public areas
  - Rest rooms
  - Parking Control Equipment

While most cleaning relates to the appearance of the parking garage and the resulting image that is portrayed to the public, some items can cause problems if neglected. For example, trash can clog drains and result in flooding, and trash left on stairs or landings may result in liability for any resulting personal injury.

In part, the suggested frequencies of cleaning are based upon the concept that people have less tendency to litter in a clean, neat environment than in an environment which is already messy. A clean, well kept parking garage promotes a good reputation and invites people to return and use the facility again. Often the increased revenue more than offsets the cost of keeping the facility clean.

One of the most frequently overlooked aspects of parking garage maintenance is proper floor cleaning. It is recommended that all parking floor areas, including curbs, be swept weekly, but no less often than monthly. Sweeping can be done either with hand brooms or mechanized sweepers designed for use in parking garages. Between sweepings it is desirable to pick up daily any litter that may appear. As noted above, litter can cause drains to clog, thus litter deserves frequent attention.

Grease and oil drippings from cars build up at parking spaces as well as entrance and exit lanes. These grease buildups should be removed with appropriate degreasers. A minimum of twice a year is recommmended. Large oil spots should be cleaned as they occur.

In addition to sweeping, a semi-annual washdown of the parking floors with a low pressure water hose is recommended for all climates. In areas where salt is used to melt snow and ice, it is especially important to wash the floors in early spring. This recommendation is also important in areas within a few miles of oceans because salt laden air, while not such a severe exposure condition, can cause problems., Sweeping should precede the washdown. More frequent washing of high traffic areas such as entrance lanes and main driving aisles is desirable and in cold climates should be performed during winter whenever moderate temperatures occur. In cold climates, if moderate temperatures do not occur, then squeegees or brooms should be used to remove salt laden slush or water. Before and after washing the floors, all drains should be checked to see that they are functioning properly. Sand washed off the floors can clog drains. Temporary burlap or straw filters may be used to prevent sand from getting into drains, but those temporary filters must be removed immediately after washing.

High pressure water jet systems should not be used on floor slabs near control or expansion joint sealants. High pressure water jets can damage sealant and cause leakage which can lead to serious deterioration. High pressure water may be used for removing grease spots on the floor slab when care is taken to avoid damage to joint sealant material.

Some floor areas should have daily cleaning by sweeping or mopping. These include lobbies or waiting areas, toilet rooms, cashier booths, offices, elevators, and entrance and exit lanes. Stairs should be cleaned on the same frequency as the parking areas unless they are heavily used. Heavily used stairs should be checked daily for trash and swept weekly.

Particular care should be given to frequent and regular cleaning of the tracks or grooves in elevator floor sills. These tracks are in both the elevator cab floor sill and each landing floor sill. Dirt in these tracks can cause the elevator doors to malfunction.

Windows in cashier booths and lobbies should be washed daily. Other windows such as those in office areas, lobbies, stairways, elevator cabs or elevator shafts, should be washed at a frequency of once a month to once a quarter, depending upon their condition.

Other areas that need to be cleaned on a regular basis include walls in rest rooms, walls in elevator cabs and walls in other areas used by the public. Trash cans should be emptied regularly, preferably daily. Stair handrails also should be cleaned, preferably each time the stairs are swept.

Parking control equipment should be cleaned weekly.

In many situations, the use of a large trash receptacle provided by a scavenger service may prove desirable.

2. DOORS AND HARDWARE

Included in this section are discussions of:

Pedestrian doors
Vehicle doors

Many varieties of pedestrian and vehicle access doors are used in parking garages. Their use is related primarily to safety and security. Doors are also used for temperature control of heated or air conditioned spaces. Pedestrian doors include those in stairways, lobbies, offices and other occupied areas. Vehicle doors include roll-down security grilles as well as overhead solid doors. It is recommended that all doors be checked at least weekly to see that they operate properly. The check of doors and hardware should include latch sets, panic hardware, door closers, hinges, locks, mechanized openings or closing equipment, and tracks on sliding, rolling or overhead doors. Some of this hardware and mechanical equipment requires lubrication at regular intervals. Lubrication should be scheduled in accordance with manufacturer's recommendations.

When a malfunction is noted, it should be corrected immediately to maintain the safety and security of the parking garage. Pedestrian doors which are blocked open usually reduce the safety and/or security of the parking garage. Blocking open such doors will likely violate local fire or building codes and could be the basis for large civil damage awards or even criminal liability. Similarly, failing to maintain security measures could lead to a successful negligence action if the failure contributed to an assault.

3. ELECTRICAL SYSTEMS

Included in this section are discussions of:

- General lighting
- Exit lights
- Emergency lighting
- Distribution panels and conduit
- Emergency power

Operating a parking garage properly requires enough lighting and power to ensure that users can move easily and securely within the facility. The most common problem with any general lighting is burned out lamps and ballasts. Lamps should be replaced regularly, either when needed as shown by regular inspections, or by scheduled replacement based on anticipated lamp life. Replacement lamps and ballasts should be stocked. Operating controls for lighting such as time clocks and photocells should be checked monthly and maintained as required. Time clocks may have to be reset monthly, especially in northern latitudes, to account for seasonal changes in dark hours.

Pedestrial "exit" lights should be visually checked daily by operating staff. Battery pack powered emergency light units are generally located close to "exit" lights and may be checked at the same time. Most units have a visible status indicator light which requires only a glance to see if the unit is working. Some units have test buttons which should be pushed at regular intervals to verify that the unit is functioning. Both the above types must be replaced immediately if not working.

Annual inspection of all electrical distribution panels is good practice. Damaged or rusting panels should be repaired, cleaned, repainted or replaced, as needed.

Electric conduit exposed to water leaks should be cleaned and protected. Damaged conduit, or that which is not well supported, or shows exposed wiring, should be replaced, and supports installed. Outlets should be working, with cover plates attached.

Inspection and maintenance of the emergency power supply is best performed by qualified people operating under an annual maintenance contract.

Electrical service for parking and revenue control equipment is covered in Section 8 and Appendix D, respectively, of this manual.

Internally illuminated signs are covered in Section 13 of this manual, however, provisions for general lighting in this section apply to sign lamps also.

Many parking garages have a base operating voltage of 277 volts for all fixtures and equipment. In many locales, only licensed electricians are allowed to do any maintenance work other than lamp changing on 277 volt systems. If such is the case, an annual maintenance contract with an electrical firm may be advantageous.

4. ELEVATORS

Included in this section are discussions of:

Elevator mechanical and safety maintenance
Cleaning of cabs and sumps
Lights

All elevators, shafts and associated hardware require periodic safety checks and maintenance services. It is recommended that this equipment be placed under a service contract with a reputable elevator service company. This service contract should include all safety and maintenance inspections required by the American National Standard Safety Code for Elevators as well as emergency service and regular lubrication and service recommended by the manufacturer. Local building codes may have additional requirements.

Hoistways and pits should be kept clean and free of dirt and rubbish. Water should not be allowed to accumulate in pits. Water leakage into the elevator shaft should be corrected as soon as it is discovered. Elevator pits and sump pumps should be checked quarterly and cleaned when necessary. See also Sections 1 and 9.

The regular cleaning of elevator cabs and shaft windows is discussed in Section 1 on cleaning. The cleaning of windows within the elevator shaft requires safety precautions and the involvement of elevator maintenance personnel.

All lights including ceiling and indicator (inside and outside cab) should be checked daily and replaced as necessary.

5. HVAC

Included in this section are discussions of:

Heating Equipment
Ventilating Equipment
Air conditioning equipment

Some garages have heating, ventilating or air conditioning equipment. This equipment requires inspection, lubrication and other service on a regular basis. In enclosed or underground parking garages, ventilation equipment should be checked daily for proper operation. It is recommended that other HVAC equipment be inspected monthly to verify that it is functioning properly. Service manuals provided by the manufacturer should be checked for appropriate maintenance action. All required servicing should be performed as specified by the manufacturer. Replacement belts and pulleys for fans should be kept in stock. To minimize the chance of a breakdown, worn or damaged belts and other parts should be replaced as soon as they are noticed. Air filters for air conditioning units or other forced air units should be cleaned or replaced regularly as recommended by the manufacturer or installer.

6. LANDSCAPING

Included in this section is a discussion of:

Landscaping

Landscaping features of a parking garage can either enhance its appearance when well maintained or be an eyesore if maintenance is neglected. Frequent - daily is preferred - removal of trash from landscaped areas is important to maintain a pleasing appearance. The need for cultivating, fertilizing, weed removal, trimming, cutting grass, etc., will depend upon the type of planting, time of year and area of the country. Contracting with a landscape maintenance service usually provides proper care. Replanting in the spring may be required due to damage from salt and/or snowplowing.

7. PAINTING

Included in this section are discussions of:

Inspection of painted surfaces - Metals
Stall striping
Concrete/masonry
Touch up
Repainting

Painting serves two purposes:

- Protection of metals against corrosion and resulting loss of structural capacity, and
- Enhancement of appearance.

Some metals such as anodized aluminum and stainless steel do not require painting. Galvanized steel surfaces do not initially require painting. However, because the galvanizing is sacrificial, under some exposure conditions, cleaning and painting may be required to maintain the corrosion protection as the surfaces age.

Paint as a protective coating depends upon its adherence to the underlying surface. Therefore, before painting any surface, it is extremely important to properly clean and prepare that surface. Preparation for painting may include removal of rust, removal of previous coats of paint, application of caulking or sealant, waterproofing concrete or masonry or other preparation appropriate to the surface and exposure conditions. Paints should be carefully selected to be appropriate for each particular application.

All painted surfaces should be inspected annually to determine their condition. Small rust spots that are observed should be cleaned and touched up each year. Complete repainting should be done as may be required by the element, type of paint and the exposure conditions. Most painted surfaces in parking garages will need repainting at intervals in the 3 to 7 year range.

Handrails and guardrails serve safety related functions. They should be inspected and painted at intervals as required to ensure retention of their structural capacity.

Regular painting of exposed metals such as doors, door frames, pipes, and pipe guards not only helps prevent corrosion deterioration but provides a pleasant and well kept appearance. Metal pan stairs must be inspected and painted on a regular basis.

Parking stall striping is a basic element of all parking garages. Stall striping should be repainted whenever the paint stripes fade or deteriorate. With the increasing number of small cars on the road, many parking facilities are being restriped to reflect the smaller size cars. It is recommended that when changing the striping, the old stripes be removed completely rather than painted over. Painting over old stripes usually results in two sets of stripes being visible and thereby confusing to the user. Paint over the old stripes often wears off ordoes not stick at all. Gravity fed paint for stall striping tends to last longer than sprayed paint.

The painting of interior or exterior concrete and masonry is usually done for appearance. Some masonry paints also serve as waterproofing. At regular intervals, these elements should be repainted. Some of the new anti-graffiti paints are effective for that purpose and should be considered when graffiti is or may be a problem.

Painting of curbs is usually safety related and they should be repainted more frequently than other elements. Semi-annual painting is recommended.

8. PARKING CONTROL EQUIPMENT

Included in this section are discussions of:

Operation checks
Preventive maintenance
Emergency service
Inventory of parts

All parking and revenue control equipment should be examined weekly and sometimes daily. A preventive maintenance program should be implemented to minimize breakdowns. A service agreement with the parking equipment supplier is recommended. This agreement should include regular preventive maintenance service as well as emergency service. Quick response to calls for emergency service, as well as local availability of replacement parts should be considered when selecting a service firm. Consideration should also be given to special training for in-house staff to take care of preventive maintenance and most emergency situations.

Copies of operation and service manuals for all equipment in the facility should be kept on hand for easy reference. It is desirable to establish a log of maintenance and service work done on each piece of equipment. It is prudent to maintain an inventory of critical components so that equipment can quickly be repaired.

More detailed information on the maintenance of parking control equipment can be found in Appendix D.

9. PLUMBING SYSTEMS

Included in this section are discussions of:

- Water supply -
  - Sanitary facilities
  - Washdown
  - Irrigation
- Water heater
- Sanitary plumbing
- Stormwater drainage -
  - Floor drains
  - Sediment basins
  - Grease traps
  - Sump pumps
- Fire protection -
  - Sprinklers
  - Standpipes
  - Fire pumps
  - Hose cabinets
  - Fire extinguishers

The water supply piping for sanitary facilities, e.g. toilets, washbasins, mop sinks, is generally protected against freezing and usually requires only a periodic check for leaks and working order. The piping for washdown and irrigation may be exposed to freezing temperatures and must be drained each fall, in addition to the above checks.

If there is a water heater, it should be checked and flushed monthly. A check of sanitary plumbing can be done with that of the water supply. The most extensive piping in a parking garage is likely to be that for stormwater drainage. Neglect of the system may have expensive consequences. Floor drain inlets and basins must be kept clear of rubbish and sediment to prevent clogging and ponding. Drains at the lowest floor may have backwater valves which should be checked for operation. When washing down the floors, temporary filters of burlap may be put over the drain inlets to keep them clear. Periodically, especially before and after washdowns, sediment basins and traps must be checked to ensure continued proper function. Sump pumps, pump motors and control switches should all be checked for proper operation. If a pump is removed for maintenance, even if for "just a few hours", a working replacement should be installed. Just a few hours could become several days and rainwater runoff could flood elevator pits with no working pump.

Fire protection sprinklers used in parking garages are usually dry systems. Equipment for the sprinklers includes an air compressor, dry pipe valve, alarm devices, and test drains. Inspection and servicing should be performed ony by qualified people. If the system is wet, or always charged, similar checks must be made. Sprinkler heads must be checked for operation and freedom from corrosion in any system.

Standpipes in parking garages are usually dry. They may be interconnected and are supplied through a siamese pumper connection at street level. The connections should be checked periodically for lubrication and damaged threads. Dry systems should be left dry and unclogged after each use. Wet systems and fire pumps must be checked and maintained by qualified people.

For all systems, the pipes, sleeves and pipehangers must be kept free of rust. See Section 7 for painting.

Hose cabinets and hoses, while required by some local authorities, are often targets for vandalism. Consequently, they should be checked often for damage. Canvas hoses should be unfolded periodically to check for age damage and replaced if necessary.

Portable fire extinguishers and their cabinets are also targets for vandalism, so should be checked frequently to see if they are in place, charged and operable. Where theft or vandalism of fire extinguishers is a problem, a glass front cabinet with a lock and/or alarm where permitted by local code, can provide security while maintaining access in the event of a fire. Extra fire extinguishers should also be kept in the parking garage office. See also Section 11.

10. ROOFING AND WATERPROOFING

The comments and information in this section are intended to apply to the many different types of waterproofing applications that may occur in a parking garage. The common waterproofing applications include:

- Roofing
- Joint sealant at construction joints, control joints and cracks in floors and walls.
- Expansion joints in floors and walls.
- Sealant at doors and windows.
- Coatings on basement walls and block walls.
- Rubber window gaskets.
- Membrane waterproofing system on floors.

Nearly all of these waterproofing systems have finite life spans. The elastomeric materials used for joint sealants and some expansion joints commonly have a life expectancy of five to twenty years. Those materials in areas exposed to direct sunlight will often have a shorter life than in areas not exposed to direct sunlight.

It is recommended that all areas of the parking garage be inspected for water leakage monthly, and in no case less than semi-annually. Where leaks occur, repair or replacement of the waterproofing element should be made as soon as practical. Spot repairs are usually the more economical until about 30 to 50 percent of that element needs repair. At that time, total replacement should be considered.

The above assumes that the leak occurs because of wear or deterioration of the waterproofing material. Other causes of leaks can be:

- Failure of the base material.
- Improper installation of the material.
- More movement at the joint than was anticipated.
- Poor selection of detail for that condition.

When one of these other causes is present, then more investigation by a qualified engineering consultant is warranted before embarking on repair or replacement of the waterproofing.

11. SAFETY CHECKS

Included in this section are discussions of:

Carbon monoxide monitors
Guardrails and handrails
Pedestrian exit signs
Emergency lights
Fire safety equipment
Emergency calls in elevators
Tripping hazards

There are some elements in a parking garage that merit some special safety checks.

Carbon monoxide monitors are often used in enclosed or underground parking garages. These monitors should be checked daily for proper performance. The instruction and operation manual for this equipment should be consulted and followed.

Metal handrails and guardrails at the edges of parking floors are subject to damage from impact and corrosion. It is recommeneded that these handrails and guardrails be checked monthly to verify that they are rigid, not damaged and can serve their intended purpose. Less susceptible to damage, but equally deserving of periodic safety checks, are concrete guard walls and stair handrails.

Most building codes require illuminated exit signs to be placed by each stairway on all floors and at other points of pedestrial egress. Many times these are white with red letters. These illuminated signs should be checked daily to see that the light bulbs are working and the sign faces intact.

Special emergency lights should be checked regularly for proper operation. See Section 3, Electrical Systems.

Fire safety equipment should be checked regularly. This includes fire extinguishers, stand pipes, hose cabinets, fire sprinkler systems and fire pumps. See Section 9, Plumbing Systems.

Elevator cabs have emergency call alarms and sometimes telephones, intercoms, or television cameras. These should be checked daily for proper operation. See also Section 4, Elevators.

Concrete floors or sidewalks can develop holes or pockets due to deterioration which can be tripping hazards. These holes or pockets should be filled immediately, even if on a temporary basis. See Section 15, Structural System, for causes of deterioration and cautions about temporary patching materials.

12. SECURITY SYSTEM

Included in this section are discussions of:

Audio monitoring
Panic buttons
Closed circuit television
Elevator cab communication
Alarms - Cashier booths
  Doors
  Elevators

It is recommended that all parts of the security system be checked daily, but no less often than weekly, to verify that all parts of the system are operating properly. Any deficiency should be corrected immediately. Security systems that are commonly used in parking garages include the following:

- Audio monitoring devices - may be located in stairs, elevator cabs, and/or parking areas. Both the monitoring devices and the sequencer/listening stations should be checked.
- Two way audio systems that may be incorporated with the audio monitoring system and/or activated by "panic buttons" placed at elevator cabs, stairways and/or other locations.
- Telephones in elevator cabs, cashier booths, or other locations.
- Alarms in elevator cabs, cashier booths, and offices.
- Alarms or other warning devices on stairway doors to indicate that they have been opened and/or are not closed properly.
- Closed circuit television in special areas or throughout the parking garage.

13. SIGNS (GRAPHICS)

Included in this section are discussions of:

Illuminated signs (internal and external)
Non-illuminated signs
Graphics painted on walls, beams, etc.

The signs inside and outside any parking garage play important roles directing and informing the users. These signs may include illuminated signs, non-illuminated signs of plastic or other materials, and signs or other graphics painted on walls, floors, beams or ceilings.

It is recommended that all mounted signs be checked weekly to verify that they are in place and that the sign illumination lamps are functioning properly. Most illuminated signs such as "full" signs and fee indicators should be checked daily.

Annually, the paint or facing material should be examined for deterioration and dirt. See also Section 1, Cleaning.

Replacement, repainting or cleaning should be done as required to maintain all signs and graphics in a clean and legible condition. Check daily to ensure that there is no obstruction to the visibility of the signs.

14. SNOW AND ICE CONTROL

Included in this section are discussions of:

- Snow plowing and removal
- Snow melting
- Ice control

As a rule of thumb, snowplow vehicle axle weights should be kept below 4,000 pounds to avoid over-stressing the parking garage. Good practice dictates checking with the garage designer to insure that the intended vehicle is not too heavy.

The snowplow blade must not be allowed to damage the concrete floor, sealants, toppings, or expansion joints. A heavy rubber cutting edge may be fitted to the bottom of the plow's steel edge, or shoes designed to keep the steel edge about one half inch above the floor may be installed on the blade. A snow broom attachment to the plow is useful for light snowfalls.

Snowfall sufficient to hamper parking operations should be removed. When snow is packed down by car tires, it becomes slippery and can become a hazard on sloping floors. Snow may be plowed to predetermined locations within the garage and simply left, or it may then be thrown over the side by a small frontend loader like a "Bobcat", or by a heavy duty snowthrower.

If the snow is left in piles, avoid overloading the floor slab beyond its design load. Piles should not be located where snow melt will flow across driving aisles. Melt water may refreeze at night, leaving ice patches in the aisle. Frozen chunks dropping from vehicles should be shoveled out of the way or disposed of daily.

If the snow is thrown over the side, avoid damaging the walls, panels, connections, sealants, or other elements.

Snow thrown over the side may be left on the ground if space allows. Care must be exercised not to pile on or against another structure. However, in congested areas, or by local ordinance, snow removal away from the garage may be required. Removal may have to occur during specific hours.

Some parking garages contain gas-fired or electric-powered snow melters. These units should be checked for proper operation each fall, and periodically during the winter months. To operate properly, these units generally must be turned on several hours before the predicted snowfall. Some units have a "snow sensor" which turns on the unit when it begins to snow. If the sensor is not effective, a manual switch should be installed.

Some parking garages have a snow melting system embedded in the floor of certain areas, such as outside stairs or a driveway. Such systems are generally one of two kinds: electrical cable, or fluid. In either case, the system should be checked for operation at the first snowfall of the season. Maintenance should follow the system manual. Breaks in cables (the electrical system) or pipes (the fluid system) are difficult to trace. Consequently, the system installer should be contacted should operational problems arise.

Another snow melting system consists of heat (infrared) lamps mounted about the surface to be kept clear. Maintenance of these lamps is similar to other types of lamps as noted in Section 3 of this manual. Lamp operation should be checked daily during the snow season.

Whatever the snow melting system, an indicator light should be installed in a highly visible central location to signify the system is operating. Some operators have learned their systems were still on in the spring after they received their power bill!

Ice buildup may be controlled by using heated sand or a mixture of sand and salt. Do not apply deicing chemicals containing chloride directly to concrete unless extremely icy conditions exist. Small amounts of salt (3 to 6 percent by weight) added to sand can be very effective at increasing traction and preventing skid problems.

Apply the sand/salt mixture to concrete only as needed. Drains should be protected agains runoff-related sand accumulation during ice control operations. Temporary burlap or straw filters should be used to prevent drain clogging and possible damage to drainage systems.

15. STRUCTURAL SYSTEM

Included in this section are discussions of:

Floors
Expansion joints
Control joints
Construction Joints
Stair and elevator towers
Beams, columns and walls
Structural steel elements

The structural system is the main part of any parking garage and usually represents the largest portion of the construction investment. Protection of that investment requires an adequately budgeted program of regular inspection and preventive maintenance. Deferred maintenance may lead to costly repairs.

The garage structural support system may be one of many available types of steel and/or concrete framing. Common to all systems is steel, whether in the form of concrete reinforcing or of structural shapes. Unless protected, steel will corrode (rust). Corrosion of the steel will weaken the garage structure at times seriously. There have been cases where a car tire has broken through a floor, and where part of a garage has collapsed because corrosion weakened the steel in the garage.

In the typical garage, the floor is subject to the most severe conditions of load, wear and exposure. The floor, containing steel reinforcement, construction joints, expansion joints, electrical conduit, electrical junction boxes, and possibly heating cable or piping may also have sprinklers, drain piping and signs suspended from it. All of the above elements combine to make the floor susceptible to premature deterioration if not properly maintained.

Types of deterioration which tend to occur in concrete floor are spalling, cracking, leaching, scaling and joint deterioration. (See Apppendix A for definitions and discussion of these terms.) Spalling, leaching and scaling may be controlled, or at least reduced, by the periodic application of a high quality protective sealer, discussed in Appendix B.

Floor slabs at entrance and exit lanes are the most exposed to deicing salts; next come gutter lines adjacent to walls and curbs. Areas where cars turn to change direction are subject to heavier wear than other floor areas. Such areas should be more closely monitored for deterioration and treated promptly. See Appendix B for maintenance.

No matter how much care is taken during construction, it seems that a garage floor will almost always have some areas where water will collect into ponds. Deicing salts will collect with the water, making the floor in the pond areas more susceptible to salt penetration. If ponds form over floor joints, the possibilities for deterioration are much greater. Areas where ponds tend to form should be checked after each rain or snow, and the ponds eliminated by sweeping or squeegeeing.

Cracks in concrete are not uncommon. The existence of a crack does not necessarily mean that the structure is in danger of collapse. Cracks are generally serious when of a type or frequency which cannot be considered typical for a particular structural member. Cracks are also a problem when they allow leakage and subsequent contamination of concrete and corrosion of embedded reinforcing. Cracks allow leaching and staining which can also cause visible deterioration of a structure. The extent and nature of cracking depends primarily on the design details and the construction methods. Cracking generally results from three basic actions: temperature movement, shrinkage of the concrete, or structural behavior.

The methods of sealing a crack against moisture penetration will depend on the cause of the crack and a prediction of what the crack will do in the future. Some crack repairs require restoration of the concrete into its original monolithic state; other cracks are best left free to move.

Some "cracks" are designed and built into the typical garage to accommodate movement and shrinkage strains within a garage, e.g. expansion joints, construction joints and control joints.

Expansion joints provide complete separation between sections of a garage and accommodate movements associated with temperature changes and long term shrinkage. Expansion joint openings are generally filled with a flexible material which may or may not be designed as a seal. Other expansion joint designs provide a steel traffic plate to bridge the opening, or may simply leave the joint open. Expansion joints of all kinds must be checked regularly for damage and deterioration. Also refer to Section 14.

Construction joints are located at predetermined points. These joints may be tooled and filled with a flexible sealant or may have cast-in-place water-stops to prevent leakage.

Control joints accommodate cracking by creating a series of weakened planes at predetermined points in the floors and walls. Control joints are tooled or formed in the plastic concrete or sawcut in the hardened concrete and then filled with a flexible sealant to prevent water penetration.

Sealants used in the joints described above do fail during service and must not be expected to last forever. Joint sealant failure occurs for several reasons: cohesion failure within the material itself, adhesion failure between the material and concrete, and incorrect joint design. Joint sealants are also subject to abrasion, freeze-thaw stressing/deterioration and ultra-violet light induced sealant embrittlement. Sealant failures can impair the serviceability of the structure. When joint sealants fail, a joint replacement and repair program should be scheduled. Joint sealant systems should be inspected frequently to determine their condition.

A typical multi-level parking garage will have stair and/or elevator towers for pedestrian movement between levels. Expansion joints are generally provided between the tower walls and the garage floors to accommodate differential movements between the towers and the garage. The joint is usually sealed, at least on the top tier, to prevent leakage. Such leaks can cause deterioration of concrete, rusting of doors, light fixture damage and electrical conduit deterioration.

Frequent inspection and repair of damaged joint sealant and flashing between tower and garage will tend to minimize leak-caused distress. Damage should be repaired soon after discovery. For extreme movement conditions, sealant replacement may be necessary, or the detail may need to be redesigned.

Landings of stair and elevator towers may be exposed to deicing salt contamination to almost the same degree as the driving surfaces, and should be given the same frequency of inspection and maintenance.

Deterioration can also affect beams, columns and walls, and is typically caused by salt-laden water leaking through joints from the floor above, by ponded water at column or wall bases, or by ponded water being splashed onto walls and columns.

Beam and column distress can also be caused by restraint, excess load, inadequate design or construction deficiencies. Conditions of this nature are beyond the scope of this manual and should be examined and evaluated by a structural engineer experienced in the design and maintenance of parking facilities.

Exposed structural steel elements such as metal decking, joists, beams, columns, lintels, connection angles, bolts, pan stairs, guardrails and handrails must be regularly inspected for rust. Rust removal, cleaning touch-up painting and complete repainting at regular intervals is required. Please refer to Section 7 for further discussion.

The structural system is an important part of the total garage and needs the same regular care as do other parts of the garage. Neglect of structural maintenance needs can lead to major problems and high repair costs. In addition to primary costs, secondary costs from lost parking revenues during garage repairs can be substantial.

APPENDIX A
CONCRETE DETERIORATION

Concrete deterioration generally falls into one of several major categories: spalling, cracking, leaching, scaling, and joint deterioration. Joint leaking also contributes to concrete distress. These deterioration mechanisms are, to varying degrees, the cause of durability problems experienced by many parking structures today.

1. REINFORCED CONCRETE SPALLING

Definition

Spalls or potholes in reinforced concrete surfaces are usually dish shaped cavities from one to several inches deep and one to several square feet in surface area. Spalls can occur individually or in groups covering several hundred square feet.

Spalling is preceded by horizontal fractures called "delaminations" which usually develop parallel to the exposed concrete surface. Fractures originate at corrosion damaged embedded reinforcement or other embedded metal and migrate to the nearest surface. Freeze-thaw, traffic action and additional corrosion influence the rate of fracture migration and spall development.

Contamination

Concrete is a naturally porous material. Excess water not required for hydration eventually dries, leaving behind an interconnected network of pores and capillaries. Concrete capillaries have diameters ranging from 10 to 1000 Angstroms in diameter. The chloride ion is less than 2 Angstroms in diameter. Penetration of chloride ions into concrete and subsequent accumulation occurs readily on surfaces exposed to deicing salts, wetting and drying and freeze-thaw cycles. Locations in coastal areas are also exposed to salts. Essentially all concrete is susceptible to chloride ion contamination by virtue of its natural porosity.

Concrete porosity can be reduced by the use of low water cement ratios and increased cement factors. By removing excess mix water, the number of pores and possibly their size is reduced.

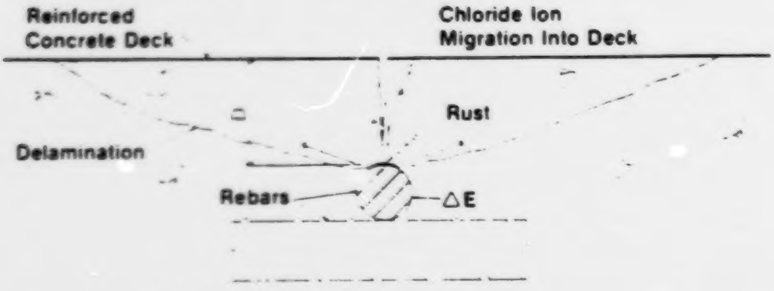
Reinforcement embedded in concrete is usually protected by a thin oxide film remaining after manufacturing and the passive effect of highly alkaline concrete. Salts, either calcium or sodium chloride, can penetrate sound high quality concrete and accumulate in sufficient quantities to cause corrosion of embedded reinforcement. Research indicates that corrosion begins when salt accumulation exceeds 1.1 to 1.6 pounds per cubic yard.

Corrosion

Metallic corrosion is a dynamic electro-chemical process and induces progressive deterioration. Corrosion by-products, "rust", develop at the steel surface causing high stress in the surrounding concrete. Rust occupies a volume at least 2.5 times that of the parent metal. The by-product accumulation causes high tensile stress (5,000 psi minimum) which cracks the surrounding concrete (see Figure 1). Initial cracking occurs when section loss of the parent metal is 5% or less. Cracks first appear vertically over the reinforcement nearest the exposed surface. These cracks allow direct access of moisture and additional chloride to the reinforcement causing accelerated corrosion and subsequent delamination.

Figure 1

Rebar Corrosion Spalling Mechanism



D = Depth of clear cover over rebars
ΔE = Differential potential (Galvanic) in rebars

Once initiated, corrosion stops only when a correcting electrical current is applied to the reinforcement network (cathodic protection) or the parent metal is entirely consumed by rusting. The corrosion process consists of two stages: the first stage is microcell corrosion and the second stage is macrocell corrosion. Microcell corrosion occurs when electrical current discharges from reinforcement at the anode and returns to the same reinforcement at a cathode. Macrocell corrosion occurs between the top mat of floor slab reinforcement which is chloride contaminated, and the bottom mat, which is usually chloride free. A battery effect occurs which causes rapid corrosion and related deterioration near the bottom mat.

The corrosion process and its subsequent effect on a reinforced member is progressive. It is generally accepted that the rate of corrosion correlates directly with the occurrence of additional delaminations and subsequent spalling. The corrosion rate is generally thought to be controlled primarily by the availability of moisture and oxygen and secondly by the surface areas of the anode and cathode. Corrosion and subsequent deterioration can be slowed by reducing the availability of moisture and oxygen.

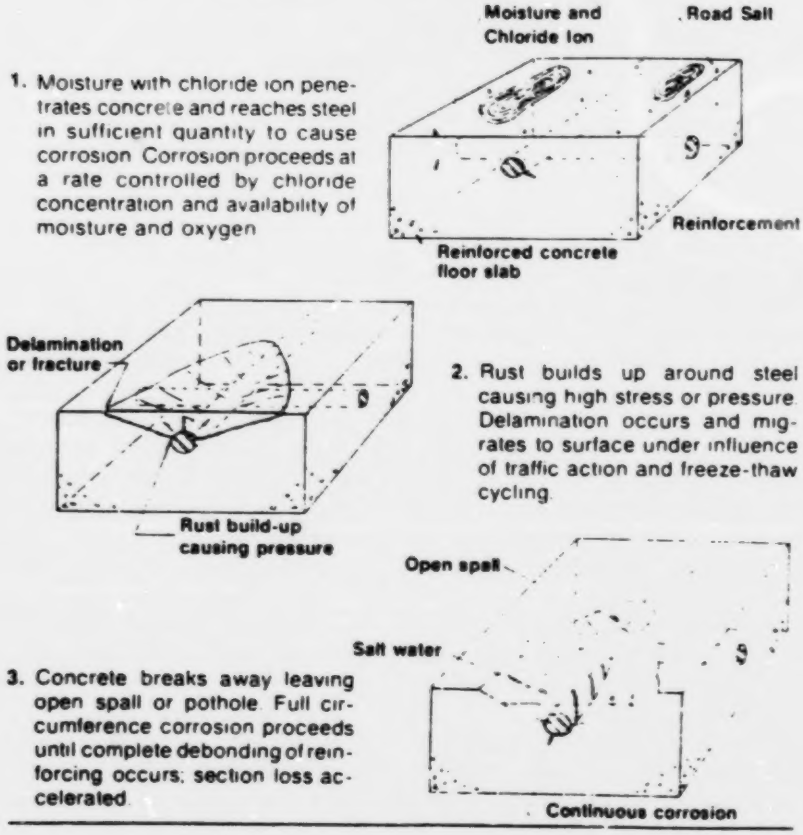
Corrosion Induced Stress

The effect that corrosion has on a structural member is variable. Five things happen, all of which are detrimental to structural integrity:

- Surface spalling occurs, causing a maintenance and serviceability problem.
- The reinforcement loses significant cross-section and stress redistribution throughout the remaining network occurs.
- The reinforcement debonds from the concrete, causing loss of monolithic interaction.
- Progressive movement of reinforcement can reduce load-carrying capacity.
- Concrete cross-section loss, in addition to reinforcement cross-section loss, impairs the load carrying capacity of floor slabs and beams. (See Figure 2)

Figure 2

Corrosion Induced Spalling Process


Moisture and Chloride Ion
Road Salt
Reinforcement
Reinforced concrete floor slab
Delamination or fracture
Rust build-up causing pressure
Open spall
Salt water
Continuous corrosion

1. Moisture with chloride ion penetrates concrete and reaches steel in sufficient quantity to cause corrosion. Corrosion proceeds at a rate controlled by chloride concentration and availability of moisture and oxygen.

2. Rust builds up around steel causing high stress or pressure. Delamination occurs and migrates to surface under influence of traffic action and freeze-thaw cycling.

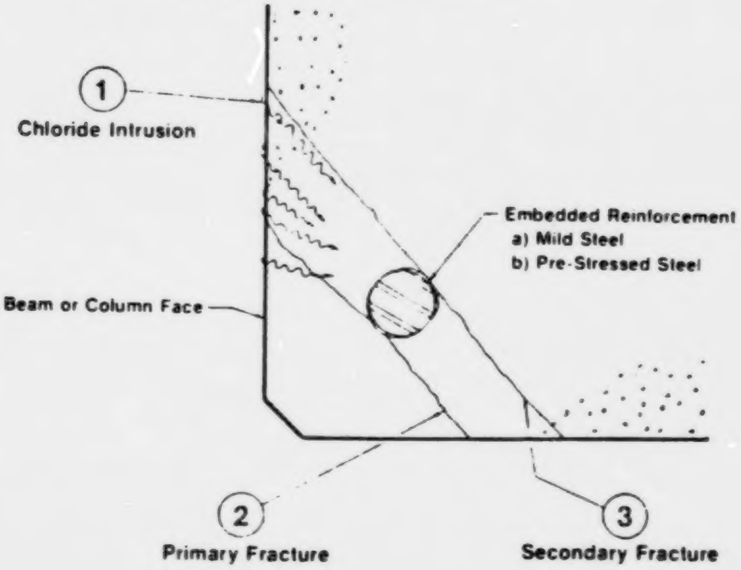
3. Concrete breaks away leaving open spall or pothole. Full circumference corrosion proceeds until complete debonding of reinforcing occurs; section loss accelerated.

One aspect of the corrosion phenomena which makes repairs so difficult is that multiple delaminations occur as the condition progresses deeper into the floor slab. Where spalling coincides with full depth floor slab cracks, it is common to find ceiling spalls directly below floor spalls. The bottom reinforcement corrodes similar to the top, thus causing a multiple effect of concrete and reinforcement section loss. Surface spalling near mid-span reduces the concrete section. At the same time, severe corrosion of bottom (tension) reinforcement can result in over stressing and possible reinforcement yielding.

Spalling may occur on all structural members. Floor slab systems frequently experience the most extensive and widespread effect of spalling (see Figure 3). Beams, columns and walls are also susceptible to spalling when subject to excessive chloride contamination from runoff or spray.

Figure 3

Spall Development Beams and Columns



Process Description

1. Chloride ion intrusion contaminates concrete - lowers pH and induces corrosion of embedded reinforcement
2. Corrosion by-products "RUST" develop at bar surface and require expansion room
3. Rust expansion causes high tensile stress which cracks surrounding concrete
4. Additional salt water gets into cracks

Influence Factors

The depth of clear cover over embedded reinforcement is perhaps the single most important aspect of design and construction which can delay the onset of spalling. Floor slabs with less than recommended cover over reinforcement, subject to intense deicing exposure, will undergo rapid and severe spalling. Floor slabs constructed with lower water cement ratio concretes, additional clear cover at top reinforcement and protected from intense deicing exposure will provide adequate service for many years.

In preparing maintenance programs for parking facilities, consideration should be given to the areas where concentrations of reinforcement occur near the surface. With flat plate designs, this involves the column capital and drop head areas. For one way slab and beam designs, the area above the beam typically has more top reinforcement than at mid-span. Maintenance efforts directed at protecting these areas from intense exposure will pay off in reduced spalling and extensions of repair-free service life.

In order to properly prepare restoration contract documents, it is necessary to first evaluate the effect spalling has had on the capacity of individual members and then to evaluate the cost effectiveness of repair procedures with regard to the total restoration program. A structural engineer must be retained to perform the required investigation, analysis and evaluations.

2. CRACKING

Concrete cracking is caused by stress. This stress is either construction or service related. Cracking commonly attributed to construction is caused by improper concrete placement, improper consolidation, improper curing of the concrete, premature removal of form supports, or by plastic shrinkage of the concrete. Service related cracking is usually due to temperature changes, load, settlement or internal stress. Corrosion of rebars and aggregate chemical reaction are common causes of internal stress.

Not all cracking is detrimental to the concrete member. In many cases, cracks are anticipated and reinforcement is provided to transfer stress across the crack. Properly positioned reinforcement arrests crack development by keeping cracks short and tightly closed. Cracking can be detrimental when it occurs to an extent and frequency not expected. If this happens, steps are necessary to minimize the effect cracking has on long term structure durability or durability of a specific member.

3. LEACHING

Leaching is caused by frequent water migration through the floor slab or cracks. As water migrates through, it takes along part of the cementing constituents, depositing them as a white film, stain, or a stalactite on the ceiling below. This process will weaken the concrete over a period of years and is accelerated by porous or perpetually moist concrete. Leaching frequently occurs from cracks beneath gutterlines.

4. SCALING

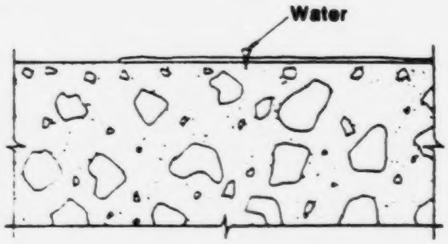
Concrete scaling is a deterioration mechanism which attacks the mortar fraction (sand and cement) of the concrete mix. It is characterized initially as a minor flaking and disintegration of the concrete surface. With passing time it progresses deeper into the concrete, eventually exposing aggregate which breaks away (see Figure 4). This further contributes to the process by exposing more paste to the elements. In extreme cases, apparently sound concrete can be reduced to a gravel-like condition in a short period of time.

Concrete scaling is caused by freeze-thaw action. When concrete is frozen in a dry state, there is little damage. If concrete is frozen in a saturated state, excess water freezing in the concrete causes high stress and weakens the mortar. Exposure to cyclic freeze-thaw action is very destructive to concrete in a saturated state.

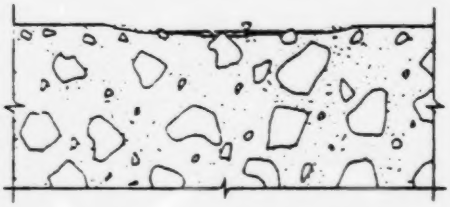
Figure 4

Concrete Surface Scaling

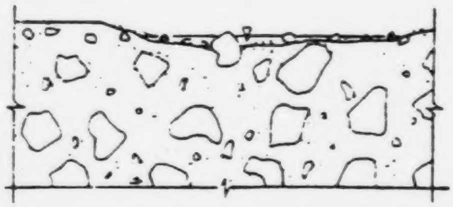
1. Concrete becomes saturated by water penetrating through pores and capillaries



2. Concrete is frozen in a saturated state causing high stress. Loose flakes appear on surface as the mortar breaks away.



3. As flaking progresses, aggregate is exposed and eventually breaks away, thereby exposing more paste to freeze-thaw damage. In extreme cases, apparently sound concrete can be reduced to a gravel-like state in a short period of time



5. JOINT DETERIORATION

The two most common provisions made for crack control or relief of restraint in concrete slabs are control joints and expansion joints. Such joints have long been a source of maintenance problems. Joints on supported floor slabs must be sealed against water leakage and intrusion of incompressibles. Both situations are damaging to the joint system.

Construction joints deteriorate for several reasons, usually associated with failure of the sealant or failure of the adjacent concrete. Joint sealants may not have the required degree of flexibility, bond, strength, or durability for particular application. If concrete adjacent to the joint is not sufficiently durable, then local scaling will cause joint sealant failure.

Expansion joints are also susceptible to premature deterioration. The most common causes of early deterioration are: improper joint design or sealant material specifications, incorrect installation of the expansion device, and in-service damage from traffic or snow plows.

APPENDIX B
CONCRETE REPAIR AND PREVENTIVE MAINTENANCE

Preventive maintenace of concrete may be divided into three categories:

1. Routine maintenance
2. Repairs
3. Renewals

1. Routine maintenance generally consists of scheduled inspection, sweeping the garage, flushing it down with water and touching up painted concrete surfaces. For painting see Section 7. Snow plowing and ice removal, two other routine maintenance items, are discussed in Section 14.

The first step to any well planned maintenance program, whether for a new or old garage, is a regularly scheduled walk-through survey - a visual inspection of the entire garage. An excellent reference for such a survey is the "Guide for Making a Condition Survey of Concrete in Service", published by the American Concrete Institute, Box 19150, Redford Station, Detroit, Michigan, 48219.

During the walk-through survey, observe the location and extent of conditions which could cause, or have already caused, concrete or steel deterioration. Items to be looked for include surface deterioration on the top and bottom surfaces of the floor systems, evidence of water leakage and/or staining through or on the floors, walls or other structural elements; cracks in floors, beams, columns and walls; and rusting of exposed steel. Leaking and staining are often indicators of future problems. Such a survey can be done by any conscientious observer, provided that if evidence of deterioration, e.g. scaling, spalling, cracks or leaks is observed, an engineer knowledgeable about garages is consulted. However, at least every two years the inspection should be made by an engineer to help ensure that no potentially serious conditions have been overlooked.

Sweeping and flushing operations are discussed in Section 1 of this manual.

2. Repairs may be classified as cosmetic (minor) or major. Minor repairs are generally those which, if left undone, do not affect the operation or the structural integrity of the garage.

An example of a minor cosmetic repair would be a repair required to refinish the corner of a concrete column knocked off by a car bumper. If there is no major damage, then the repair may be made by cleaning and patching with new concrete or any of several commercially available patching materials as noted below.

Major repairs to concrete include those for scaling, spalling, cracking and leaking. Repairs to membranes, sealers and sealants are discussed in Appendix C.

The first step in repairing concrete damage of any kind is to determine the nature and extent of the problem. The walk-through survey is a start, but it must be understood that a visual survey reveals only visible deterioration.

A review of the walk-through survey results may indicate the need for a more comprehensive survey which would include testing for subsurface fractures and delaminations and/or deicing salt contamination. Despite the most thorough investigation, some hidden deterioration may be revealed only after the start of repair work.

Repairs to scaled and spalled areas must be undertaken with care. Improper repairs hide, but do not cure, the problem. An example is a temporary asphalt patch over a spall. Asphalt is porous and will permit salt-laden water to collect unseen at the bottom of the spall. If steel reinforcement is exposed at the bottom of the spall, the salt water will attack the steel and the resulting corrosion of the steel and weakening of the floor will become visible only after the corroding steel has caused a larger spall.

Repairs to scaled or spalled areas may range in complexity from simple cleaning and sealing, to isolated patching, to installation of a protective membrane, to installation of a thin overlay, or complete reconstruction. Cleaning has been discussed in Section 1. Sealing is discussed in Apppendix C.

Patching is a generally effective repair for isolated spalls. A good patch must be durable and must bond well to the concrete substrate. Patch edges should not be feathered because the feathered edge usually fails. The patch must also react to temperature changes in the same way concrete does, and be compatible with it. Early failure of many organic patching materials is directly due to the differences in coefficients of expansion between the patch material and the underlying concrete.

While many patching materials have been tried, the most widely used and effective are generally of portland cement concrete. Other successfully, but not widely used patching materials, are various epoxy and polymer concretes. Polymer concretes are classed as thermosetting and hydrating. Examples of thermosetting polymer concretes are those containing epoxy and those containing methyl methacrylate. Examples of hydrating polymer concretes are those containing styrene-butadene ("latex") additives which enhance bond and reduce permeability. In all cases installation of patching should be performed by a contractor experienced in similar work and capable of maintaining an acceptable standard of patch quality and installation suitability.

American Concrete Institute (ACI) Standard Specifications for epoxy systems - ACI Standards 503.1-79 through 503.4-79 are good references. The American Society for Testing Materials (ASTM) standard material specification

"ASTM C 881-79 Epoxy Resin Based Bonding Systems for Concrete" will also be helpful, but in all cases check expansion coefficients for compatibility with conventional concrete. If none are given, do not assume either compatibility or satisfactory performance.

When the total area to be patched is a significant part of the floor area, an overlay becomes more cost-effective than isolated patches. An overlay can also modify floor gradients to improve drainage and eliminate ponding.

Overlays will add thickness to the original floor system. Headroom will then be less than was originally designed the structure the weight (dead load) will be higher. These considerations must be examined by a qualified engineer to ensure that the overlay does not cause more problems then it solves.

Two concrete overlays have been used extensively for the past fifteen years and have been found to be highly effective: low-slump high density concrete (LSDC) and latex modified concrete (LMC). Conventional portland cement concrete has also been used, but less extensively than either LSDC or LMC.

LSDC - also called "the Iowa Method" - overlay consists of a low water-cement ratio, high cement content concrete which has reduced permeability to water and deicing salts. Workability problems characteristic of LSDC can be solved by using proper additives. This overlay should not be considered if its weight will be a problem.

LMC overlays use a special admixture in the plastic concrete which reduces permeability to water and deicing salts, and is more effective with less thickness than LSDC. The reduced quantities required for an LMC overlay may be offset by its higher unit costs compared to LSDC, so cost comparison should be made for the specific project.

Conventional concrete overlays consist of a cement-rich mix with usual slump and water reducing admixtures which reduce permeability to water and deicing salts, but may be a somewhat less durable overlay than either LSDC or LMC at somewhat less cost.

Polymer concrete overlays have been used only on a limited scale and have not been fully evaluated. Such systems, whether referred to as polymer or epoxy concrete can, however, offer solutions to surface deterioration problems, and should not be excluded from consideration.

Overlay cost comparisons should be made only for the specific use intended. General cost comparisons tend to be misleading due to the effects of specific quantities and construction constraints or in-place costs.

If there are many leaks in the floor, installation of a protective membrane (see Appendix C) may be the solution. Isolated leaks may be eliminated by proper crack repairs (see Appendix C and Section 15).

It may be that by the time maintenance action is taken, deterioration has progressed to the point where the only effective repair is complete reconstruction, a course beyond the scope of this manual.

A good reference is the ACI Compilation No. 5, "Concrete Repair and Restoration". It contains a broad range of articles on the subject of concrete repairs.

3. Renewal maintenance of concrete within a parking garage primarily involves repair and/or replacement of sealers and sealants. See Appendix C.

In summary, simply cleaning the garage is the best maintenance for concrete. A clean garage will develop fewer concrete problems than one left untouched. Should deterioration occur, engage only qualified engineers and contractors with proven records of good parking garage maintenance and repair.

APPENDIX C
WATERPROOFING, PREVENTIVE MAINTENANCE AND REPAIR

Waterproofing systems discussed in this Appendix are:

- Roofing on stair and elevator towers
- Protective sealers for floors
- Sealants for floor and wall joints
- Caulking
- Protective membranes on floors
- Foundation waterproofing

Roofing may be one of a number of types. It should be inspected from the underside for leaks during scheduled cleaning of the tower interiors. Some of the newer roofs consist of a thin waterproof membrane applied over cellular insulation, which in turn rests on the roof structure. This membrane is easily punctured, so walking on the roof should be avoided. Bubbles in the roofing material, be it a membrane or the more common built-up type, are indications of deterioration and should be eliminated before they break and admit moisture. In most cases, repairs are best made by a reputable roofer equipped to work on the particular roofing system.

A protective sealer is a liquid applied to protect and preserve concrete by filling the concrete pores and by sealing the concrete surface against penetration by water-borne deicing salts and other deterioration-causing contaminants. A quality material, properly applied and renewed periodically, will also provide supplemental protection against freeze-thaw damage, corrosion and wear. No sealer is a cure-all, however, and the concrete to which it is applied must be basically sound for the sealer to be effective. Sealers do wear off under use and are subject to ultraviolet light attack, so must be reapplied at intervals ranging from one to five years, depending on the product, rate of application and conditions of exposure and use. Life cycle costs must be evaluated in making a choice of sealers.

With so many sealers on the market, and more coming, seek professional advice as to which is best suited for a particular use and exposure. Some help in evaluating sealers may be obtained from a review of ASTM C672.76, "Standard Test Method for Scaling Resistance of Concrete Surfaces Exposed to De-Icing Chemicals" and of the 1981 National Cooperative Highway Research Program Report 244 "Concrete Sealers for Protection of Bridge Structures". As of the first half of 1982, no ASTM test exists which satisfactorily measures penetrating sealer performance. One is being developed and will be available in updates of this manual. Report 244 does describe a test program.

Once a sealer is selected, it should be applied by a manufacturer approved contractor in accordance with the manufacturer's instructions. Too heavy an application may produce a slippery glaze on the concrete surface which will reduce traction and increase the possibility of cars skidding. The same caution applies to application of sealer on stairs, landings and lobby floors. Before newly sealed surfaces are reopened for patron use, the sealed surfaces must be checked for slipperiness. This check must be with surface moisture both present and absent. This suggested safety procedure is, of course, in addition to any others which are required by prudent business practice.

Sealants are used to seal control and construction joints in walls and floors against moisture intrusion into the joint. The materials may be self-leveling or non-sag, depending on whether they are intended for use on horizontal or vertical surfaces. Sealants are intended to remain relatively soft and flexible throughout their service lives and are designed for exterior use. They seal properly prepared joints through adhesion to the surrounding concrete. Sealants for relatively narrow joints are applied to joints in horizontal surfaces by pouring, and to vertical surfaces by a caulking gun. Sealants should meet or exceed the requirements of Federal Specification TT S-002270E, for Sealants, Class A, Type 1 and 2, self-leveling and non-sag.

Expansion joint sealants have the same function as those for control and construction joints. Expansion joints are more vulnerable to wear, however, because they are directly exposed to wheel traffic. For that reason, though poured expansion joint sealants similar in formulation and installation to control and construction joint sealants are available, prefabricated sealants installed by experienced factory-approved contractors tend to give better performance.

All sealants must be inspected periodically for wear. Sealants, being soft and flexible, are susceptible to tire abrasion and tearing by improperly used snowplows. Sealants which have failed will cause deterioration to the concrete substrate and to the steel reinforcing. Loss of reinforcing due to corrosion can have serious consequences.

The manufacturing and/or installer of the sealant should be consulted for proper materials and methods of repair. Also review sealant warranties: some products come with warranties as long as five years. Depending on the type and exposure conditions, most sealants have a useful life of 8 to 10 years and must be removed and replaced. When old sealants are removed, examine the underlying concrete for deterioration, make necessary repairs and apply penetrating sealer to the concrete before installing the new sealant. As a rule of thumb, when 30% of the sealant joints in the structure need repair or replacing, it is time to start planning for replacement of the sealant in all joints.

"Caulking" is often used to mean "sealant", and vice versa, but the two terms are not really synonymous. Caulking, unlike sealant, is intended for interior use, and will harden and it can crack, in time. It should be examined during the annual walk-through inspection. Maintenance usually consists of removal, cleaning and replacement of old caulking.

Protective membrane systems are generally installed to eliminate widespread leaks through a floor slab in an older garage, or to provide additional insurance against leaks in a newer one. Several membrane systems are available, the most durable of which seems to be the two layer system. Membranes should be carefully maintained; repairs may be needed within three to five years.

Drive-on membranes can be visually inspected. Membranes protected - and hidden - by a separate wearing surface cannot. Damage to the hidden membrane is usually first indicated by leaks from the ceiling on the underside of the floor covered by the membrane. Finding and repairing such leaks may require tearing up the wearing surface above the leak so that the membrane can be patched. Drive-on membrane damage is easier to locate and repair. Consult the membrane installer and/or manufacturer for proper repair materials and methods. The membrane may have a warranty, which should be checked to see if it still in effect.

Damage to foundation waterproofing usually shows up after that waterproofing has been made inaccessible by backfilling around the garage. Sometimes leaks in basement or retaining walls below outside ground level may be sealed from the inside, using any of a number of available techniques including quicksetting grouts, pressure injected epoxies or other materials. If that fails, bentonite, a finely divided clay which swells considerably when wetted, may be injected into the outside ground adjacent to the leak. Bentonite installers with specialized equipment operate under a number of trade names and can be found in most metropolitan phone books. Be sure to check the installer's references.

If all other repairs fail, the earth next to the foundation wall may have to be excavated and the waterproofing repaired directly. Other repairs are possible, but are beyond the scope of this manual. Consultation with a qualified soils engineer or structural engineer should be considered.

APPENDIX D
GENERAL MAINTENANCE PROCEDURE OF BASIC PARKING CONTROL EQUIPMENT

To keep parking control equipment in good running condition, it is important to follow certain maintenance procedures. One of the first and most critical steps in a sound maintenance program is to read the service manual for each piece of equipment thoroughly. Call the manufacturer if a problem does arise.

The following outline provides general guidelines for maintaining parking control equipment, which should extend the life of the equipment and thereby lower overall operating costs.

A Ticket Dispenser

1. Keep entire ticket dispensing mechanism free of ticket dust. This is especially important for the cutter assembly. Use a long handled artist's paint brush with stiff bristles. Do this monthly.
2. Lubricate the cutter with white grease after first removing all ticket dust. Use an artist's brush to apply the grease on sliding surfaces. Perform at the same frequency as #1.
3. When splicing tickets, make sure that the gummed tape is across the full width of the tickets. After affixing the taped edges of a new ticket supply to the last ticket of the old supply, fold this area at the taped location. Using a pair of scissors, cut the corners (as shown in Diagram A) on a 45° angle. By doing this each time tickets are added, the possibility of a ticket jam due to splicing can be reduced.
4. Apply white grease to ribbon advancing mechanism index cam (where index cam microswitch contacts outer edge of cam). White grease is recommended because its viscosity remains constant in cold weather. Lightweight oil can be used on the clutch. Perform monthly.
5. Adjust the ticket cut so that the tab is in the back end of the ticket as shown in Diagram B.
6. Most dispensers have ticket interlock switches. If the switch is out of adjustment, two problems may occur. Either no ticket will be issued, or if it is issued, the gate will not rise. Check the manufacturer's service manual for adjustment procedures.
7. During days of high humidity, turn the heater on to keep the tickets dry. Damp tickets will usually cause a ticket to jam. Both this and the correct splicing procedure are especially important for preventing ticket jamming.

B. Auto Gates

There are two basic types of gate drives; harmonic action with a vee belt and a gear reducer and chain drive with sprocket reduction. In most cases, the following tips will apply to both types of drives.

1. Gear Reducer Gates: The belt drive from the motor reducer input is the weakest link in the drive train. After a period of six to eight months, the vee belt(s) will tend to stretch, causing the drive motor to coast because of less friction. This one item will cause many operational problems. Gate arms will prematurely come down on vehicles because the cam for the up stop limit switch will coast off the up limit and cause the gate arm to return to the down position. In some cases, the gate arm will continue in this oscillating mode indefinitely. This may cause damage to vehicles, gate arm, and internal drive components. The following are some preventive measures:

   a. Make sure vee belt(s) tension is correct and is checked periodically -usually 45 to 60 days.

Diagram A

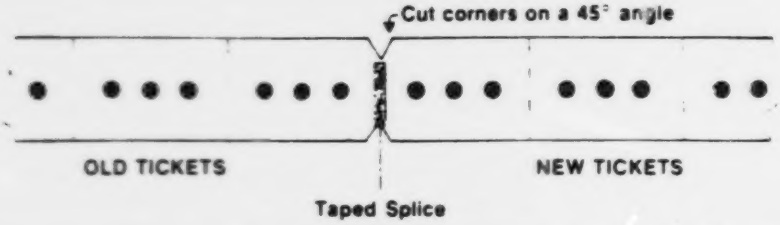
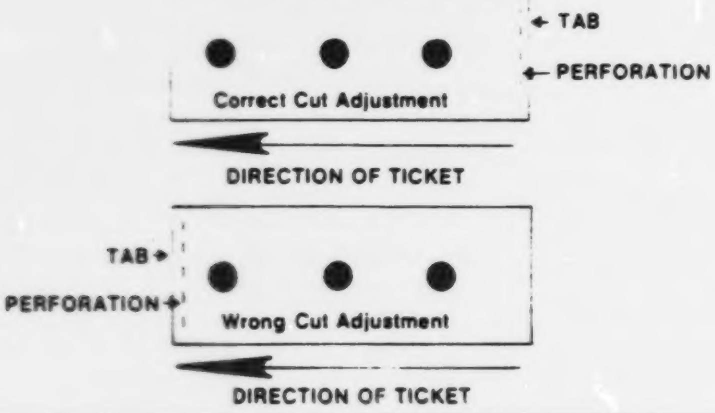

Cut corners on a 45° angle
OLD TICKETS
NEW TICKETS
Taped Splice

Diagram B


TAB
PERFORATION
Correct Cut Adjustment
DIRECTION OF TICKET
TAB
PERFORATION
Wrong Cut Adjustment
DIRECTION OF TICKET

b. Replace vee belt(s) every six to eight months regardless of external conditions.

c. When shear pin (drive pin) needs replacement, replace with the manufacturer's recommended size. Check gate arm flange and main output shaft to be sure there is no movement between these two components. The use of an oversize shear pin, together with drilling the correct hole size to eliminate any movement, is acceptable.

d. A loose flange on the main output shaft will cause a gate arm whiplash effect, causing severe strain back into the drive train, causing bearing wear, and possibly loosening reducer mounting bolts which may cause further problems.

2. Check heater and thermostat before each winter season. The heater is important not only for any electro-electronic components, but also for gates with reducers, to keep the gear fluid at the correct viscosity.

3. Check gear fluid every six months, or more frequently, when leakage is present. If the gear box leaks, contact the manufacturer.

4. Gates with relay logic will need motor drive contacts cleaned with emery cloth every six months. This will prolong contact life.

5. Check and tighten all nuts, belts and screws every 60 days.

6. As a normal procedure, replace both up and down limit switches every twelve months. In time, arcing and pitting of contacts will promote limit switch failure, allowing the motor to run continuously and possibly causing the gate arm to lower prematurely.

7. Check all sockets and connectors every three to six months. Vibration may cause them to become disconnected, resulting in equipment malfunction and vehicle damage.

8. The exterior painted surface should be cleaned and waxed every four months. The exterior surface may need cleaning and waxing more frequently, depending on the environmental conditions of the area.

C Detectors and Loops

1. A grounded loop in the pavement will cause erratic operation and should be corrected or replaced immediately. Clues to a grounded loop are that often, during damp or rainy weather, the detector will constantly go into a detect mode, causing incorrect operation including no ticket issuing, no gate reset, constant raise operation, or may cause the gate arm to reset prematurely, possibly causing damage or injury.

2. Make sure that loop leads have a minimum of four turns per foot and are spot-taped to prevent loop lead-in from separating. This will ensure proper detector operation.

3. A suggested loop sealant is a good quality butyl-based compound.

D Card Access System

There are many types of card reader access sytems used in the parking industry today. The most common type is the manual operation magnet matrix reader.

Keep reader clean. Follow manufacturer's instructions. If possible, use an air gun to dislodge dirt, wipe clean, clean matrix card, reinsert back in reader and check for smooth operation. If a problem still exists, then magnet replacement is necessary and this should be done at the factory.

E Spare Parts and Replacements

It is recommended that spare parts be kept on hand at all times.

The following is a basic checklist of common replacement parts:

1. One each dispenser controller
2. One each gate controller, for pay and free gates
3. Drive pins (for gate arm flange)
4. Ribbons (for dispenser and outclocks)
5. Limit switches for dispensing mechanisms and gates
6. Assorted cotter pins (DO NOT USE PAPER CLIPS)
7. One each detector
8. Gate arms
9. Reducer oil (check manual for correct viscosity)
10. Interlock switch
11. Heater strip

PARKING CONSULTANTS COUNCIL MEMBERS

William C. Arons
Walkin, Inc.
Minneapolis, Minnesota

Richard S. Beebe
Richard S. Beebe & Associates
Des Plaines, Illinois

Charles Boldon
International Parking Design, Inc.
Sherman Oaks, California

G. Victor Brisson
Dome Parking, Inc.
Pontiac, Michigan

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PRC Voorhees
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DesMan Parking Associates
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Seymour Gage Associates
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NAM Engineering - Cleveland
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The Office of Carl Walker
Kalamazoo, Michigan

E. M. Whitlock
Wilbur Smith & Associates
New York, New York

Ben W. Young
Intertech Engineers, Inc.
Dallas, Texas

APPENDIX B
CONDITION SURVEY FORMS

CITY OF
PARKING FACILITY SURVEY

ADDRESS OF BUILDING ______________________________

LOT NO. ______________________________

PLAN NO. ______________________________

APPLICATION NO. ______________________________

OWNER ______________________________

____

____

____

PROPERTY MANAGER ______________ TELEPHONE NO. __________

SUPERINTENDENT ______________ TELEPHONE NO. __________

OVERALL RATING ______________

DATE ______________

INSPECTOR ______________

Application No. __________

____

Date: ______________________

Inspector: ______________

CITY OF ______
PARKING FACILITY
SURVEY

A. GENERAL INFORMATION

A. Address: ____

____

A-1. Date of last revision on plans: ____________________________

A-2. Parking Spaces: ______________ Roof: ____________________

Underground: __________

A-3. Approximate Utilization: Roof _____% Underground _____%

A-4. Built for present owner/ Purchased by present owner(circle one)

A-5. Type of structure (Flat slab, Flat slab with drop panels, one-way slab, flat slab with drop panel and capitals)

A-6. Past Restoration: ______________________________________

A-7. Above ground or below ground. Enclosed or open.

A-8. Heated or unheated.

A-9. Separate structure or part of building. (circle one)

A-10. Utilization Type (office, commercial, industrial, condominum, rental)

A-11. Number of levels excluding roof : ____________________________

B. DESIGN DATA - (from plans)

B-1. Structural drawings available: ____________________________

B-2. Air-entrainment specified : ________________________________

B-3. Specified cover: ____

B-4. Waterproofing/sealing specified ___________________________

(circle one, if answer is yes).

B-5. Expansion Joint Type: ____________________________________

B-6. Expansion Joint Locations : _______________________________

B-7. Design Live Load: Roof__________

p.s.f._____ kPa

Intermediate Slabs______ p.s.f.

_____ kPa

C. SUMMARY OF RATINGS

	Topside Visual	Underside Visual	Over-All Rating
C-1. Roof Slab	_____	_____	_____
C-2. Interior Slabs	_____	_____	_____
C-3. Suspended Ramps	_____	_____	_____
C-4. Other Components			_____

C-5. Overall Parking Structure Rating: __________

C-6. Comments regarding serious structural defects: ________________

____

____

____

D. ROOF

D-1. Approximate Area: ________ square feet ________ square metres

D-2. Overburden

		Approximate % of Garage Roof
a)	Landscaping, sodding, trees, shrubs, playgrounds, etc.	________________
b)	Asphalt covered	________________
c)	Enclosed, no overburden	________________

D-3. Top Surface of Asphalt Wearing Course

(a) Cracks in the Surface

(i) **Amount of Cracks**

_____ None

_____ Few (1 m long per 20 m^2)

_____ Many (1 - 5 m long per 20 m^2)

_____ Numerous (5 m long per 20 m^2)

(ii) **Width of Cracks**

_____ Barely Visible

_____ Easily Visible

_____ 0.5 mm or less

_____   0.5 mm

(b) Patches and Potholes

_____ None

_____ Some

_____ Many

_____ Numerous

(c) General Condition of Surface Asphalt

_____ Very good

_____ Good

_____ Fair

_____ Poor

_____ Very Poor

D-4. Underside of Roof (specify general location i.e. under landscaping, asphalt-covered, etc)

(a) Cracks in the Concrete with Associated Leached Deposits/Rust Stains

(circle one or cross both out)

_____ None

_____ Few (1 m long per 20 m^2)

_____ Many (1 - 5 m long per 20 m^2)

_____ Numerous (5 m long per 20 m^2)_________________________

(b) Scaling of Concrete

_____ None

_____ Slight (1 % of Total Area)

_____ Moderate (1 - 2 % of Total Area)

_____ Severe (2 % of Total Area)___________________________

(c) Concrete Spalls - Amount of Spalling

_____ None

_____ Few (1 % of Total Area)

_____ Moderate (1-2 % of Total Area)

_____ Numerous (2 % of Total Area)________________________

(d) Exposed Reinforcing Bars

(i) **Amount of Exposed Bars**

_____ None
_____ Few
_____ Many
_____ Numerous ______________________________

(ii) **Condition of Bars**

_____ Unrusted
_____ Slightly Rusted
_____ Moderately Rusted
_____ Severely Rusted

(e) Wet Spots

_____ None
_____ Slight (1% of Total Area)
_____ Moderate (1-2% of Total Area)
_____ Severe (2% of Total Area)______________________________

(f) General Condition of Roof Underside

_____ Poor
_____ Very Poor
_____ Fair
_____ Good
_____ Very Good

E. INTERIOR SUSPENDED SLAB(S) (for each slab)

E-1. (a) Level No.____________________
(b) Approximate total area of interior suspended slab(s) __________
(square metres)
(c) Slabs waterproofed? _____ yes _____ no _____ partial
(d) Waterproofing system ______________________________
(e) Other coverings and estimated thickness ____________________

E-2. Top Surface of Interior Suspended Slabs

(a) Cracks in the Surface

(i) Amount of Cracks

_____ None

_____ Few (1 m long per 20 m^2)

_____ Many (1 - 5 m long per 20 m^2)

_____ Numerous (5 m long per 20 m^2)

(ii) Width of Cracks

_____ Barely Visible

_____ Easily Visible

_____ 0.5 mm or less

_____ 0.5 mm

(b) Concrete Spalls - Amount of Spalls

_____ None

_____ Few (1% of Total Area)

_____ Moderate (1-2% of Total Area)

_____ Numerous (2% of Total Area)

(c) Concrete Delamination:

estimated ____________________%

by chain-dragging ____________________%

by automatic sounder____________________%

(d) Active Corrosion

________% of __________readings

(e) Cover:

__________ readings (top reinforcing only)

Average : __________mm

Lowest : __________mm

Highest: __________mm

Exposed Bars in spalls __________

No cover on isolated bars in areas of sound concrete____________

(f) Exposed Reinforcing Bars

(i) Amount of Exposed Bars

_____ None

_____ Few

_____ Many

_____ Numerous

(ii) Condition of Bars

_____ Unrusted

_____ Slightly rusted

_____ Moderately Rusted

_____ Severely Rusted

(g) Scaling of Concrete

_____ None

_____ Slight (1 % of Total Area)

_____ Moderate (1 - 2 % of Total Area)

_____ Severe (2 % of Total Area)

(h) General Condition of Surface of Interior Suspended Slab(s)

_____ Very Good

_____ Good

_____ Fair

_____ Poor

_____ Very Poor

E-3. Underside of Interior Suspended Slab(s)

(a) Cracks in the Concrete with Associated Leached Deposits/Rust Stains

_____ None

_____ Few (1 m long per 20 m^2)

_____ Many (1 - 5 m long per 20 m^2)

_____ Numerous (5 m long per 20 m^2)

(b) Scaling of Concrete

_____ None

_____ Slight (1 % of Total Area)

_____ Moderate (1 - 2 % of Total Area)

_____ Severe (2 % of Total Area)

(c) Concrete Spalls - Amount of Spalling

_____ None

_____ Few (1 % of Total Area)

_____ Moderate (1-2 % of Total Area)

_____ Numerous (2 % of Total Area)

(d) Exposed Reinforcing Bars

(i) **Amount of Exposed Bars**

_____ None
_____ Few
_____ Many
_____ Numerous

(ii) **Condition of Bars**

_____ Unrusted
_____ Slightly rusted
_____ Moderately Rusted
_____ Severely Rusted

(e) Wet Spots

_____ None
_____ Few
_____ Many
_____ Numerous

(f) General Condition of Underside of Interior Suspended Slab(s)

_____ Very Good
_____ Good
_____ Fair
_____ Poor
_____ Very Poor

F. SUSPENDED RAMP(S)

F-1. (a) Number of suspended ramp(s) ______________________________
(b) Approximate total area of suspended ramp(s) ________________ (square metres)
(c) Ramps waterproofed? _____ yes _____ no

F-2. Top Surface of Suspended Ramps

(a) Cracks in the Surface

(i) **Amount of Cracks**

_____ None
_____ Few (1 m long per 20 m^2)
_____ Many (1 - 5 m long per 20 m^2)
_____ Numerous (5 m long per 20 m^2)

(ii) **Width of Cracks**

_____ Barely Visible
_____ Easily Visible
_____ 0.5 mm or less
_____ 0.5 mm

(b) Concrete Spalls - Amount of Spalling

_____ None
_____ Few (1% of Total Area)
_____ Moderate (1-2% of Total Area)
_____ Numerous (2% of Total Area)

(c) Exposed Reinforcing Bars

(i) **Amount of Exposed Bars**

_____ None
_____ Few
_____ Many
_____ Numerous

(ii) **Condition of Bars**

_____ Unrusted
_____ Slightly rusted
_____ Moderately Rusted
_____ Severely Rusted

(d) Scaling of Concrete

_____ None
_____ Slight (1 % of Total Area)
_____ Moderate (1 - 2 % of Total Area)
_____ Severe (2 % of Total Area)

(e) General Condition of Surface of Ramp(s)

_____ Very Good
_____ Good
_____ Fair
_____ Poor
_____ Very Poor

F-3. Underside of Suspended Ramps

(a) Cracks in the Concrete with Associated Leached Deposits/Rust Stains

_____ None
_____ Few (1 m long per 20 m^2)
_____ Many (1 - 5 m long per 20 m^2)
_____ Numerous (5 m long per 20 m^2)

(b) Scaling of Concrete

_____ None
_____ Slight (1 % of Total Area)
_____ Moderate (1 - 2 % of Total Area)
_____ Severe (2 % of Total Area)

(c) Concrete Spalls - Amount of Spalling

_____ None
_____ Few (1 % of Total Area)
_____ Moderate (1-2 % of Total Area)
_____ Numerous (2 % of Total Area)

(d) Exposed Reinforcing Bars

(i) **Amount of Exposed Bars**

_____ None
_____ Few
_____ Many
_____ Numerous

(ii) **Condition of Bars**

_____ Unrusted
_____ Slightly rusted
_____ Moderately Rusted
_____ Severely Rusted

(e) Wet Spots

_____ None
_____ Few
_____ Many
_____ Numerous

(f) General Condition of Underside of Suspended Ramp(s)

_____ Very Good
_____ Good
_____ Fair
_____ Poor
_____ Very Poor

G. OTHER COMPONENTS

G-1. Ledge Beams*

Cracking ____________________
Spalling ____________________
Binding ____________________
Exposed Bars ____________________
Leakage ____________________
Expansion Joint Movement: Accommodated/Not Accommodated (circle one)
(Elaborate - if not accommodated i.e. associated concrete distress)____________________
____

G-2. Expansion Joints Movement* (Roof)

Cracking/separation from concrete____________________
Leakage____________________
Rust Staining____________________
Adjacent Spalling ____________________
Adjacent Exposed Bars____________________

G-3. Expansion Joints* (Suspended Slabs)

Cracking/separation from concrete Leakage____________________
Leakage____________________
Rust Staining ____________________
Adjacent Spalling ____________________
Adjacent Exposed Bars ____________________
Expansion Joint Movement: Accommodated/Not Accommodated (circle one)____________________
____

G-4. Expansion Joints* (Vertical Elements)

Cracking/separation from concrete ____________________
Leakage ____________________
Rust Staining ____________________
Adjacent Spalling ____________________

Expansion Joints * (Vertical Elements), cont'd.

Adjacent Exposed Bars ____________________

Expansion Joint Movement: Accommodated/Not Accommodated (circle one)____________________

____

G-5. Columns/Beams*

Cracking____________________

Spalling____________________

Exposed Bars____________________

Honey combing ____________________

G-6. Perimeter Walls*

Block/Poured Concrete (circle one)

Cracking____________________

Leakage____________________

Spalling____________________

Exposed Bars____________________

G-7. Drainage System*

Slab Slopes____________________

No. of Drains____________________

Size of Drains____________________

Size of Headers____________________

Drainage Disposal____________________

G-8 Drains

Functioning ______ properly ______ clogged

Leakage around drain * ____________________

Leakage through headers * ____________________

Adjacent concrete deterioration * ____________________

G-9 Stairwells, Airshafts and Handrails

Comment: ____________________

____

____

G-10. Electrical Fixtures

Conduits _____ surface mounted _______ imbedded in slab

Leakage * ______________________________

Corrosion * ______________________________

Exposed Wires * ______________________________

Illumination Level ______________________________

*** Fill in: none/few/some/many/numerous where appropriate and as previously defined.**

TYPICAL STRUCTURAL FAILURES
(ANSWER YES OR NO)

REINFORCED CONCRETE STRUCTURES

FLAT SLABS AND FLAT PLATES

PUNCHING SHEAR ________

EXCESSIVE DEFLECTION ________

EXCESSIVELY WIDE CRACKS ________

CLOSELY SPACED CRACKS** ________

UNEXPLAINED POROSITY ________

UNDERSIDE SPALLING HAZARDOUS ________

BEAMS, JOISTS, GIRDERS

EXCESSIVELY WIDE OR LONG SHEAR CRACKS ________

EXCESSIVE DEFLECTION ________

EXCESSIVE MID-SPAN CRACKING ________

EXCESSIVE LOSS OF BEARING AREA ________

LONG HORIZONTAL CRACKS ________

COLUMNS AND PERIMETER WALLS

EXCESSIVE SETTLEMENT ________

SHEAR FAILURES ________

** Particular attention to underside of roof below garbage pick-up areas.

SPLITTING __________

LOSS OF CONCRETE COVER __________

BOWING __________

ANY THROUGH COLUMN CRACKING __________

IN-FILL BLOCK WALLS

UNSTABLE __________

MOVEMENT

SLIDING BEARINGS DO NOT SLIDE __________

POST-TENSIONED

SIGNS OF DUCT LEAKAGE __________

ANY FLEXURAL CRACKING __________

MOVEMENTS AFFECTING VERTICAL ELEMENTS __________

PRE-CAST

BEARING LENGTH INSUFFICIENT __________

BEARING DETERIORATION __________

SPALLING OF TEE STEMS __________

NEOPRENE PADS __________

DESCRIBE SLIDING BEARINGS

____

____

____

____

____

ANY FLEXURAL CRACKING ________

LEAKAGE ________

MOVEMENT ________